1953

The effect of initial deflection on the stress distribution in a panel of ship's plating under tensile load

Haskell, Arthur Jacob; Wurlitzer, Robert Edward

Cambridge, Massachusetts. Massachusetts Institute of Technology

THE EFFECT OF INITIAL DEFLECTION ON THE STRESS DISTRIBUTION IN A PANEL OF SHIP'S PLATING UNDER TENSILE LOAD

ARTHUR JACOB HASKELL
AND
ROBERT EDWARD WURLITZER

1953

M-38

NAVY DEPARTMENT
OFFICE OF COMMANDING OFFICER
U. S. NAVAL ADMINISTRATIVE UNIT
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE. 39. MASSACHUSETTS

8 June 1953

From: LTJG A. J. HASKELL, USN (Member of the Naval Construction and Engineering, NB3 Group, M.I.T.)
To : Superintendent, U. S. Naval Postgraduate School
Via : Commanding Officer

Subj: Thesis pages; forwarding of

Ref: (a) Ltr from Sr. Member, Naval Construction and Engineering, NB3 Group, M.I.T. of 28 May 1953, with CO, USNAU, MIT, first-endorsement NC1/1 P11-3(Th)(NB3) Ser 398 of 28 May 1953 (Restricted)

Encl: (1) 2 sets of 13 superseding pages for 2 copies of theses (total of 26 pages)

1. Reference (a) submitted among others two copies of a thesis entitled "The Effect of Initial Deflection on the Stress Distribution in a Panel of Ship's Plating under Tensile Load", prepared by LTJG's A. J. Haskell and R. E. Wurlitzer, USN. It is requested that enclosure (1), thesis pages numbered as follows, be inserted in the two copies of the above-named thesis and that the pages thereby superseded be destroyed:

Page 18
Figure XIII, Page 22
Figure XXXIII, Page 44
Figure XXXIV, Page 45
Figure XXXV, Page 46
Figure XXXVI, Page 47
Figure XXXVII, Page 48
Figure XXXVIII, Page 49
Figure XXXIX, Page 50
Figure XL, Page 51
Page 55
Page 56
Page 60

A. J. HASKELL
Lieutenant (jg), USN

- -

FIRST ENDORSEMENT NC1/1, P11-3(Th)(NB3), Ser 442
9 June 1953

From: Commanding Officer
To : Superintendent, U. S. Naval Postgraduate School

1. Forwarded.

J. M. HICKS

THE EFFECT OF INITIAL DEFLECTION ON THE STRESS DISTRIBUTION IN A PANEL OF SHIP'S PLATING UNDER TENSILE LOAD

by

ARTHUR JACOB HASKELL
Lieutenant Junior Grade, U. S. Navy
B.S., United States Naval Academy
(1947)

ROBERT EDWARD WURLITZER
Lieutenant Junior Grade, U. S. Navy
B.S., United States Naval Academy
(1948)

SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
NAVAL ENGINEER

at the

MASSACHUSETTS INSTITUTE OF
TECHNOLOGY

May 1953

ABSTRACT

THE EFFECT OF INITIAL DEFLECTION
ON THE STRESS DISTRIBUTION IN A PANEL
OF SHIP'S PLATING UNDER TENSILE LOAD

by

Arthur J. Haskell, Lieutenant
Junior Grade, U. S. Navy

Robert E. Wurlitzer, Lieutenant
Junior Grade, U. S. Navy

Submitted to the Department of Naval Architecture and Marine Engineering on 25 May 1953 in partial fulfillment of the requirements for the degree of Naval Engineer.

The object of this work was to commence an investigation whose ultimate aim would be to quantitatively relate the maximum stress in a ship's panel under uniform tension to the amount of deflection initially present in that panel. The results of such an investigation may provide information related to ship failure and may further provide plating deflection criteria for shipbuilders.

The method of testing was as follows:

1. An 18" x 6" x 1/8" stiffened panel, representative of ship's plating, was constructed and welded to pulling members adapted to fit a 300,000 pound tensile testing machine. One of the two panels tested was plane, the other had deflection roughly equal in magnitude to the plate thickness.
2. SR-4 rectangular rosette strain gages were utilized to obtain the strain pattern on both sides of the plate.
3. The samples were then tested, strain readings taken at loads from 20,000 to 140,000 pounds at 20,000 pound increments.

Calculations were performed to obtain the pattern of principal strains existing on the plates. The test results were then modified to represent a condition of uniform strain along the edge.

The results showed that the points of maximum deflection of the distorted plate supported very little of the load, while very high

stresses existed near the stiffeners. This did not appear to be the case for the plane panel. It was considered that the results of the two tests conducted did not yield sufficient information to quantitatively relate stress distribution and initial deflection.

Recommendations for future work included the following suggestions:

1. Construction and testing of more samples of varying amounts of deflection and aspect ratio.
2. Investigation of the possibility of modifying the design of the pulling members to obtain a more uniform load condition at the edge.
3. Integration of stress curves at edge and center of plate to verify test data.
4. Eventually preparation of plots of maximum deflection to plate thickness ratio versus ratio of maximum stress to uniform stress along plate edge.

Thesis Supervisor: John Harvey Evans
Title: Associate Professor of Naval Architecture

Cambridge
Massachusetts
May 25, 1953

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled, "The Effect of Initial Deflection on the Stress Distribution in a Panel of Ship's Plating under Tensile Load".

Respectfully yours,

ACKNOWLEDGMENT

The authors wish to acknowledge their indebtedness to Professor J. H. Evans for his helpful advice and criticism and to those members of the Mechanical Engineering, and Naval Architecture and Marine Engineering Departments without whose cooperation this thesis could not have been written.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF TABLES

I INTRODUCTION

The significant number of failures of merchant and naval vessel structures in recent years have led to many investigations into the causes of these failures. On page 10 of reference (1) it was concluded that, "The fractures in welded ships were caused by notches and by steel which was notch sensitive at operating temperatures. When an adverse combination of these occurs the ship may be unable to resist the bending moments of normal service". Notches, whose presence is considered necessary to initiate failure may be caused in several ways. Notches resulting from fabrication or inadvertently built into the design (as at hatch corners) have been previously considered. High stress concentrations in a localised area of ship's plating may cause a local fracture which may form the notch needed to initiate failure.

A theory advanced to the authors by Professor J. H. Evans, of Massachusetts Institute of Technology relates the variation in stress concentration to the amount of initial bulge in the panel between stiffeners of a section of ship plating. Suppose, for example, initial bulge exists in a section of a transversely framed ship's hull. In addition let us assume that the section is in tension (as a section of the bottom shell would be with the ship sagging). The section of the plating containing the bulge will be unable to assume its apportioned share of the load until the deflection is removed. The section of the plating adjacent to the longitudinal members will therefore receive and maintain a disproportionately high part of the load. It is conceivable that the high stresses developed could cause cracking, and subsequent

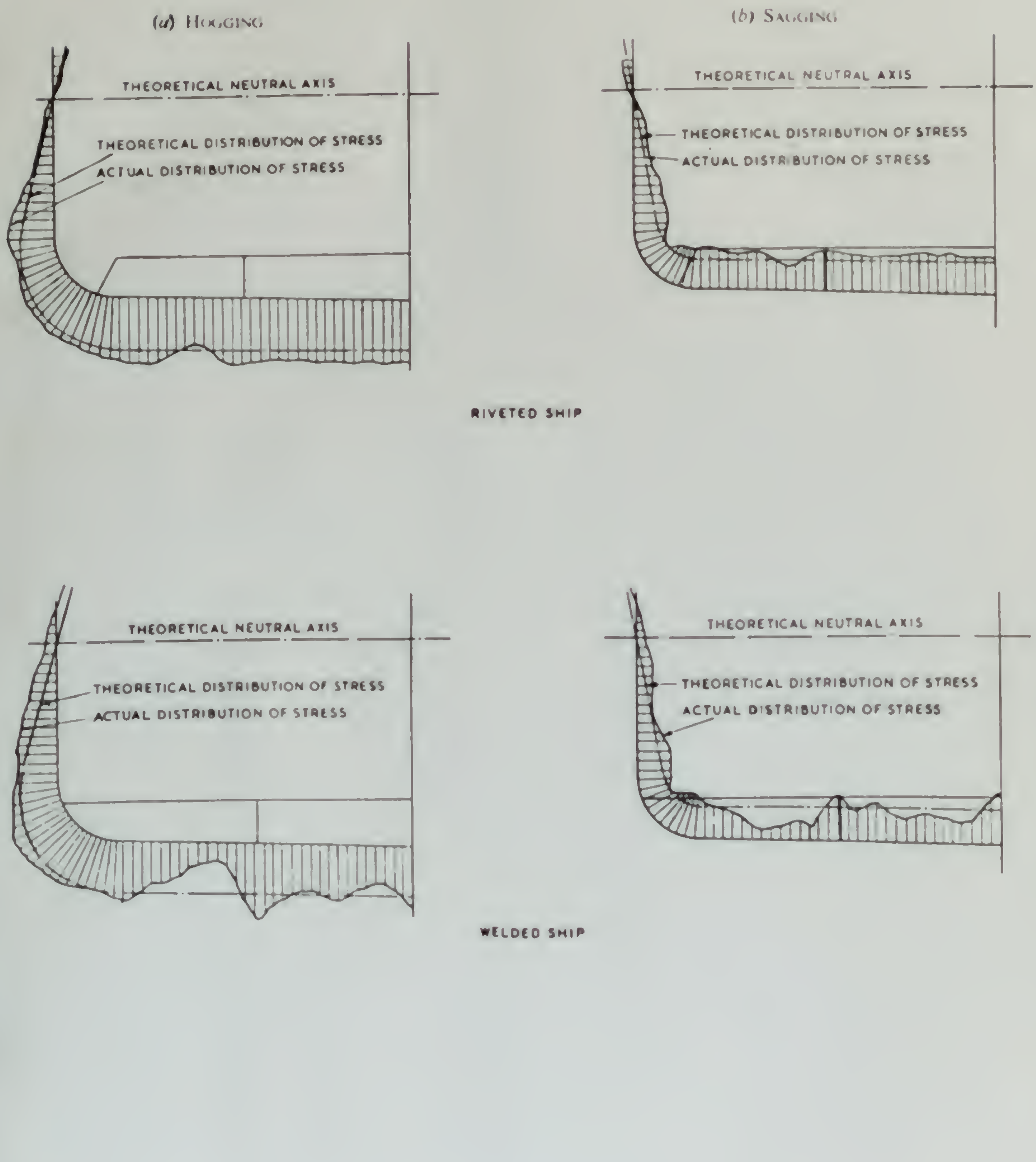
failure, in this region before the distorted section began to carry its portion of the load.

Several investigations have included observations which tend to substantiate the foregoing ideas. The authors' research has not disclosed any work which relates initial deformation to stress distribution. The Admiralty Ship Welding Committee reports of the full scale tests on the Neverita, Newcombia, Ocean Vulcan, and Clan Alpine are reviewed by Turnbull in reference (2). The findings of interest to this report are well summarized in Figure I,(reproduced from reference 2). The stresses in the way of the longitudinal stiffeners of the welded ship for both hogging and sagging are much greater than the stresses clear of that stiffening. Note that this is not as true for the case of the riveted ship. The report states: "The unfairness of the bottom plating between frames clear of the longitudinal stiffening in the welded Ocean Vulcan was in general about double that of the riveted sister ship". Thus the difference in stress from the center of the panel to the stiffeners would be expected to be less in the riveted ship than in the case of the welded ship.

These observations indicate that it is probably true that initial distortion has an effect on stress concentration. That this effect is great enough to initiate ship failure has not been determined. The idea motivating the authors was to commence an investigation whose ultimate aim would be to quantitatively relate the maximum stress in a ship's plate under uniform tension to the amount of bulge initially present in that plate. It is felt that the results of this investigation

FIGURE I

Distribution of longitudinal stresses for bottom shell plating near amidships for merchant vessels.



may provide information related to ship failure and may further provide plating deflection criteria for shipbuilders.

II PROCEDURE

2.1 Design of Test Section

The design and construction of the samples together with the selection of the testing machine were the first problems faced. It was considered desirable to test a sample representative of ship's stiffened plating. The design of the test section was governed by several practical considerations. The thinnest plate that it was considered practical to weld by the conventional continuous process was 1/8 inch thick. The longitudinal stiffeners were selected to provide adequate stiffness with the minimum cross-sectional area. The width of the sample, 24 inches, was then determined by the 300,000 pound capacity of the tensile testing machine available. The fracture load of the machine was limited to 225,000 pounds. This corresponds to an average stress of 60,000 p.s.i. for the sample as designed. Longitudinal stiffeners were then placed 18 inches apart. The distance between transverse stiffeners was set at 6 inches to give an aspect ratio of 3:1 inside the stiffeners, considered to be a representative value.

The specimen constructed for testing is illustrated in Figures II and III. It consists of the test panel to which are welded the pulling members. The 12" x 24" test panel is constructed of 1/8 inch medium tensile steel, minimum tensile strength 60,000 p.s.i., maximum carbon content 0.31%, Federal Specification M-48-S-5, Grade M. The transverse angles are $1\frac{1}{2}$" x $2\frac{1}{2}$" x 3/16" and the intercostal longitudinal angles are 1-3/8" x 7/8" x 3/16". The angle material is Federal

RGW
4-28-53

FIGURE II

TEST SECTION AND PULLING MEMBERS

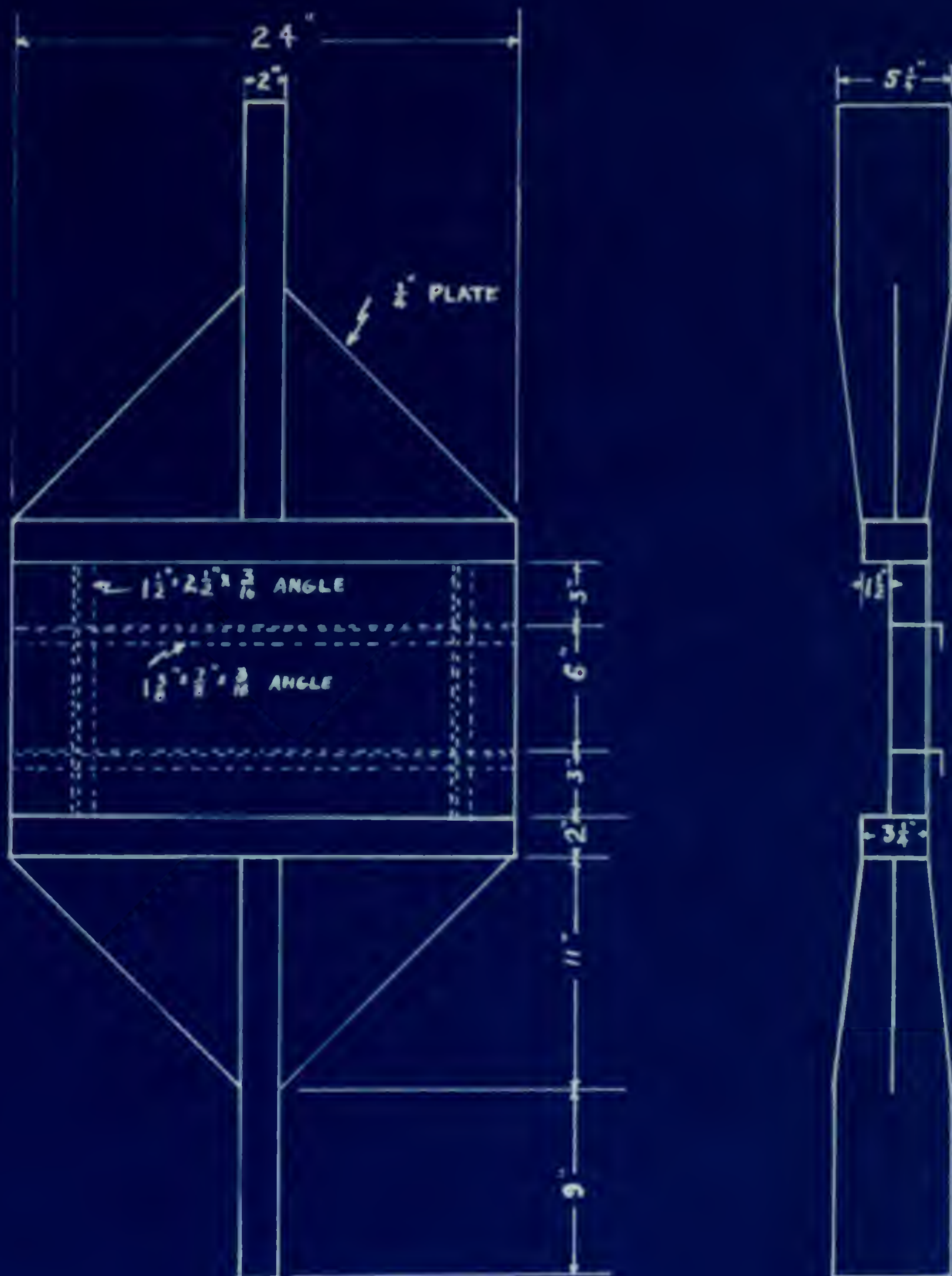
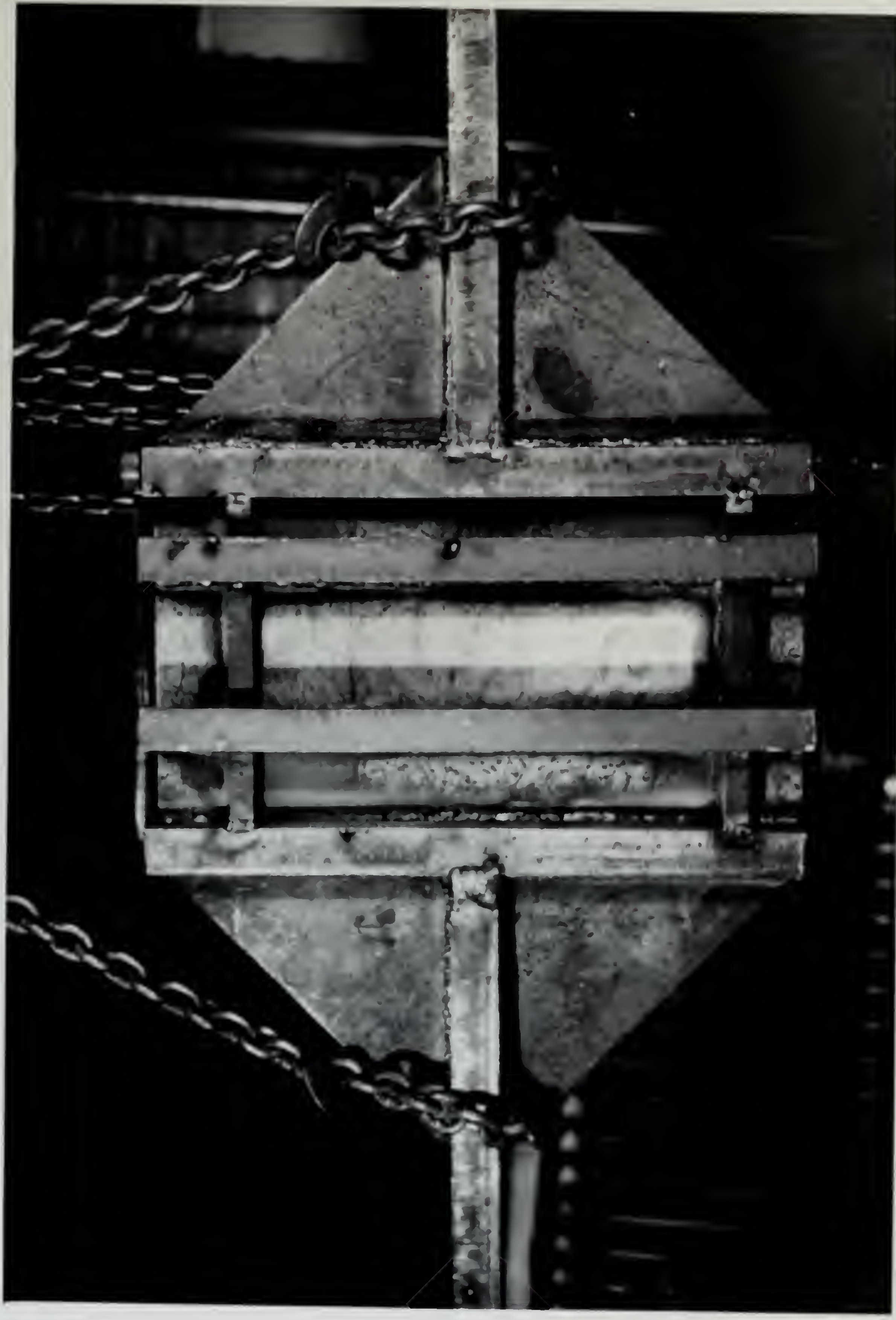


FIGURE III

Test Section and Pulling Members



Specification M-46-S-1, Grade M, Type A, hot-rolled carbon steel, minimum tensile strength 60,000 p.s.i.

2.2 Design of the Pulling Members

Adapting the specimen to be fitted into the jaws of the testing machine and at the same time providing a condition approaching uniform tension along the length of the test section were the controlling factors in the design of the pulling members. The design of these units included the following features:

2.2.1 A 24 inch long, 2 inch thick steel plate is welded to the specimen. This relatively thick plate was selected to help transform the essentially point load of the machine to a uniform tensile load at the sample.

2.2.2 1/4 inch gusset plates were fitted to assist in obtaining the uniform tension desired.

2.2.3 The $5\frac{1}{4}$" x 2" dimensions at the pulling member head gave adequate cross-sectional area to transmit loads up to 300,000 pound limit of the machine. This area was reduced as the vertical member approached the sample. This safely reduced the weight of the pulling members, since the lost area was supplied by the gusset plates.

2.2.4 The pulling members were constructed of the same material as the 1/8 inch plate.

2.3 Joining Test Section and Pulling Members

The design provided for a welded joint between test section and pulling members. The connection was made so that the neutral axis of

Specification M-46-S-1, Grade M, Type A, hot-rolled carbon steel, minimum tensile strength 60,000 p.s.i.

2.2 Design of the Pulling Members

Adapting the specimen to be fitted into the jaws of the testing machine and at the same time providing a condition approaching uniform tension along the length of the test section were the controlling factors in the design of the pulling members. The design of these units included the following features:

2.2.1 A 24 inch long, 2 inch thick steel plate is welded to the specimen. This relatively thick plate was selected to help transform the essentially point load of the machine to a uniform tensile load at the sample.

2.2.2 1/4 inch gusset plates were fitted to assist in obtaining the uniform tension desired.

2.2.3 The 8½" x 2" dimensions at the pulling member head gave adequate cross-sectional area to transmit loads up to 300,000 pound limit of the machine. This area was reduced as the vertical member approached the sample. This safely reduced the weight of the pulling members, since the lost area was supplied by the gusset plates.

2.2.4 The pulling members were constructed of the same material as the 1/8 inch plate.

2.3 Joints: Test Section and Pulling Members

The design provided for a welded joint between test section and pulling members. The connection was made so that the neutral axis of

the pulling member coincided with the neutral axis of the plate-stiffener combination. This was done to eliminate bending as much as was possible.

2.4 Fabrication

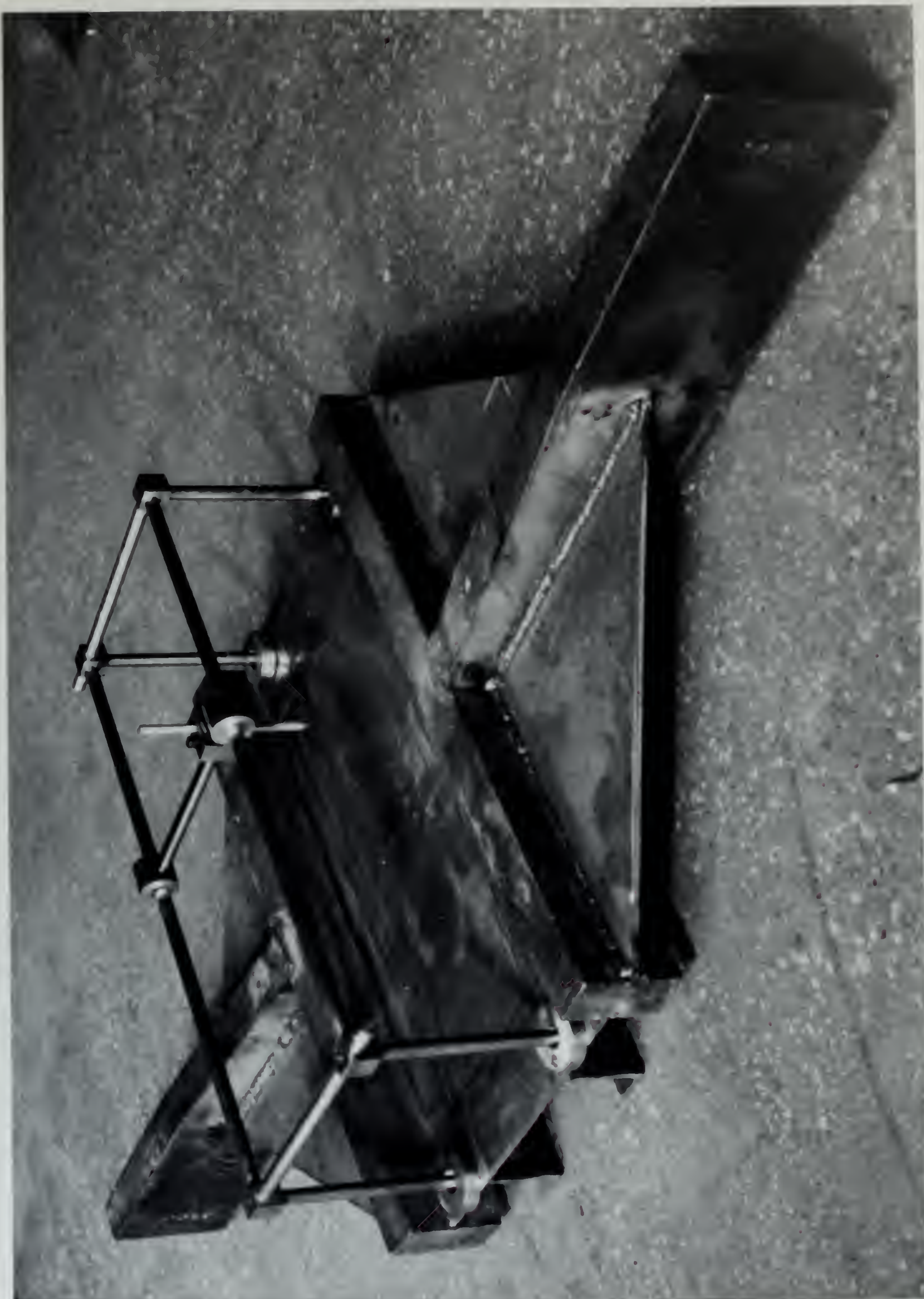
The construction of the samples was undertaken by the Shipfitter Shop of the Boston Naval Shipyard, Boston, Massachusetts. The fabrication process used for construction of the undistorted sample was as follows. The sample was dogged down and the weld deposited around the inside of the stiffeners using a block and backstep sequence. The same process was repeated around the outside of the stiffeners. It was originally decided to attempt to introduce distortion into the samples by varying the welding sequence. It was found that the unsupported length between transverse stiffeners was not great enough to allow distortion of the depth desired. It was finally decided to heat a sample with an oxy-acetylene torch. By heating and air cooling the center section of the specimen it was possible to introduce the desired amount of distortion in the plating. It is estimated that the sample did not exceed a temperature of 1700° F during the process, so that it is considered that the metallurgical structure of the steel did not change from its previous condition.

2.5 Contour Measuring Device

In order to measure the distortion of the samples a contour measuring device was constructed. (See Figure IV). It consists of four brass legs whose vertical height may be adjusted by means of threaded

FIGURE IV

Contour Measuring Device



base pieces. On the cylindrical supports between the legs rides a horizontal carriage whose position can be varied along the length of these supports. On the carriage is a holder for a dial-gage which can be moved back and forth on the carriage. The measuring process consists of first adjusting the plane of the measuring device parallel to the theoretical plane including the four points of intersection of the stiffeners on the unstiffened side (henceforth referred to as the reference plane). This can be done as long as the plane has not twisted. The amount of distortion in the panel between stiffeners is than measured. A contour map can then be prepared with the data obtained.

2.6 Preparation of Panel 1 and Equipment for Test

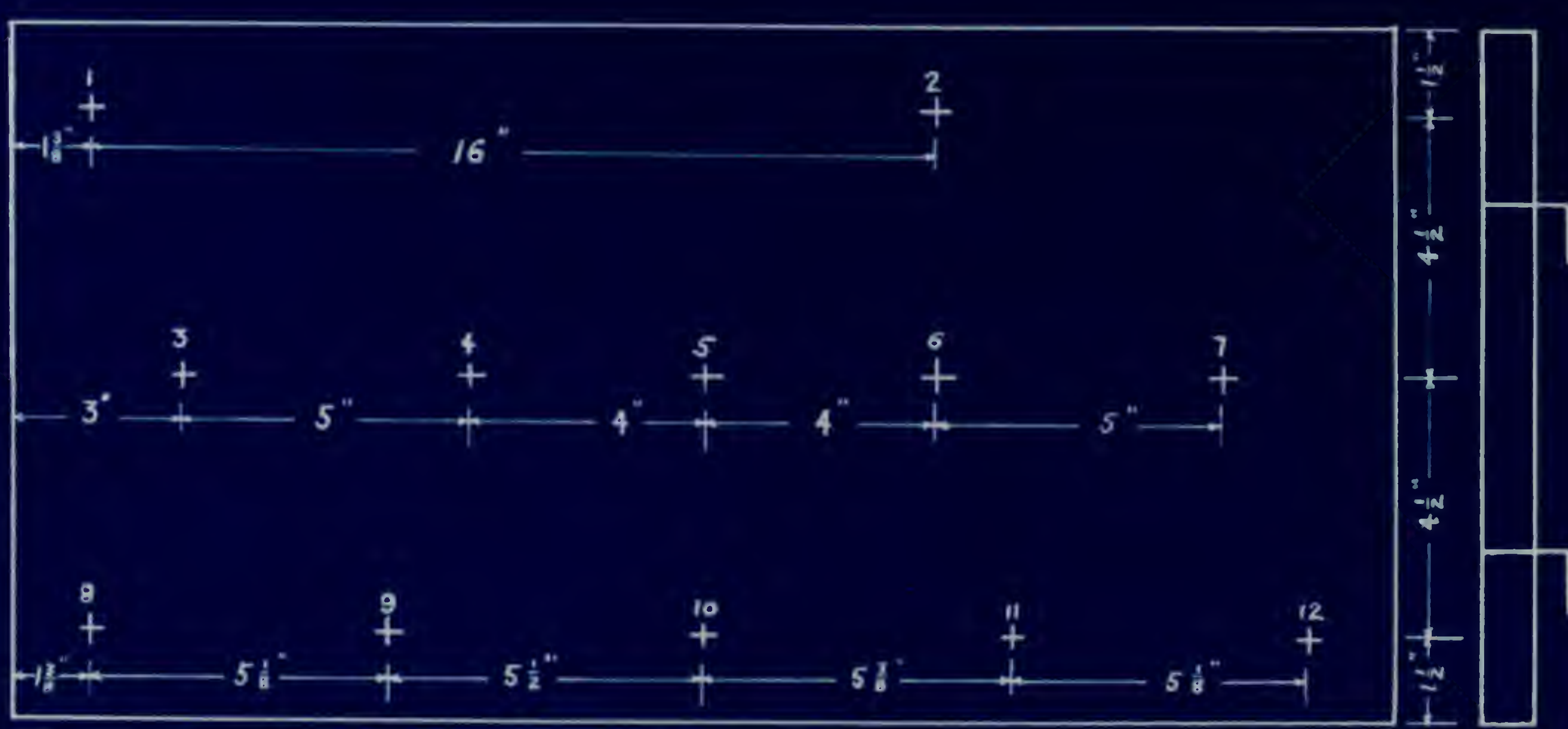
It was decided to use a relatively plane sample for the first test. The panel selected, henceforth referred to as Panel 1, was determined to be within $\pm$ 0.003 inches of the reference plane.

The strain gages selected to measure the plate strains were Baldwin SR-4 Type AR-1. These are rectangular (45°) rosettes, whose component gage lengths are 13/16 inch. Rosettes were selected because it was desired to determine the angle between the axis of principal strain and the axis of pull. The location of the rosettes is depicted in Figures V and VI. The gage locations on the stiffened side are drawn as if the panel were transparent and an observer were looking through from the unstiffened side. The gage locations were selected to attempt to obtain an over-all picture of the strain distribution. Gages on the edge were located to determine if uniform tension along the edge was obtained and if symmetry about the center of the panel was realizable. Particular interest in the nature of the strains near the stiffeners is reflected by

KEW
4-30-53

Figure V

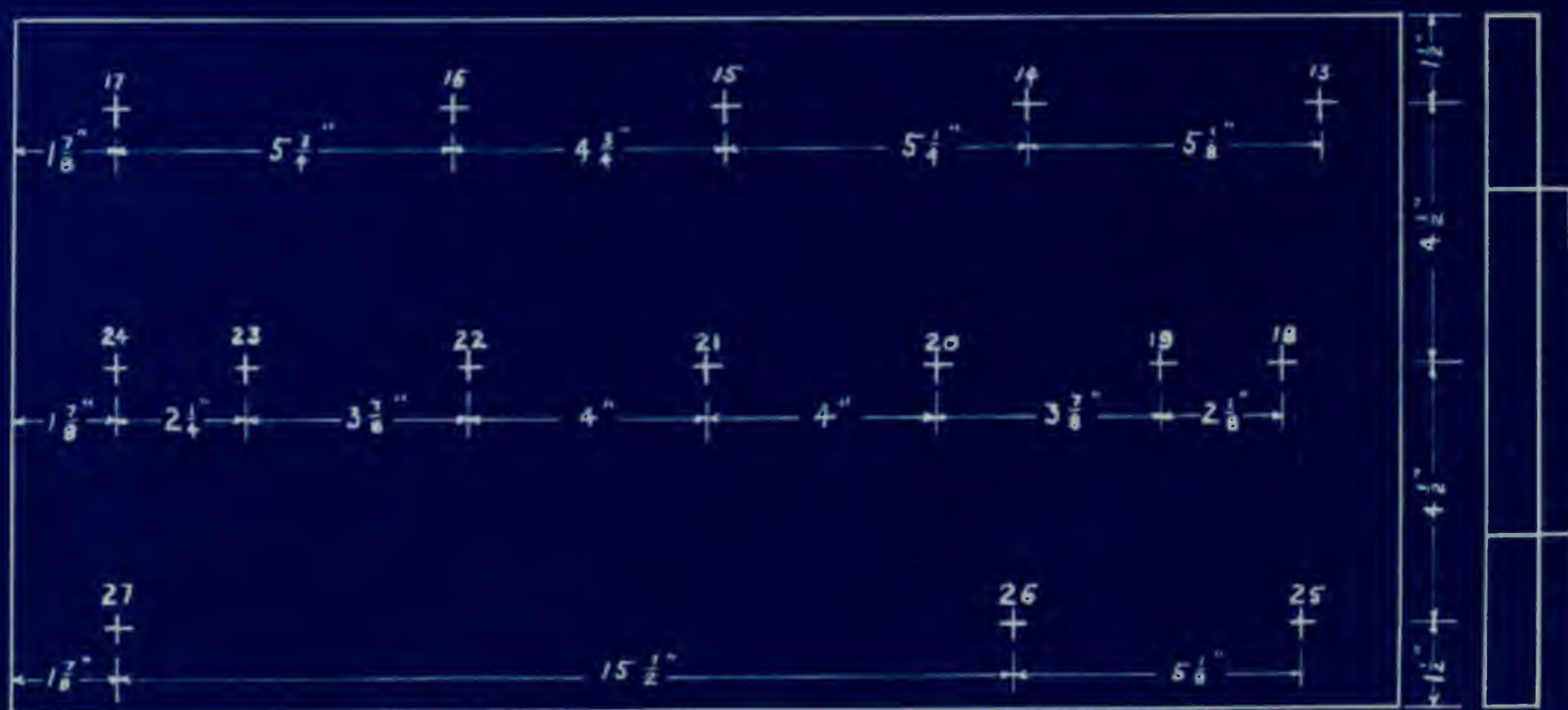
Location of strain gages on unstiffened side of panel one



R.E.W.
8-1-53

FIGURE VI

LOCATION OF STRAIN GAGES ON STIFFENED SIDE OF PANEL ONE LOOKING THROUGH PANEL FROM THE UNSTIFFENED SIDE.



the locations of gages 3, 7, 24, 23, 19, and 18.

The question of obtaining rapid, reliable, readings on the strain indicator unit (a Baldwin SR-4 Indicator Box, Type K) was the next problem faced. The 27 rosettes necessitated 81 readings. The only switching unit available capable of handling that number of gages was a rotary-switch unit. Variable contact resistance was found to exist during preliminary testing. The magnitude of this variable resistance introduced errors too large to be tolerated (in some cases resistance changes measured several hundred micro-inches per inch). A switching unit (Figure VII) was constructed consisting of 41 double-throw, single-pole, copper knife switches of 25 ampere rating. These switches reproduced readings within 10 micro-inches per inch during preliminary tests.

2.7 Test of Panel 1

The machine upon which this test and the test of Panel 2 was conducted was a Southwark-Emery hydraulic type testing machine, capacity 300,000 pounds, M. I. T. Serial 105. The control panel for this machine is shown in Figure VIII. The sample mounted in the machine is pictured in Figure IX.

The following procedure was employed for the test of Panel 1.

2.7.1 The sample was cycled by raising the load to 5000 pounds and returning to zero load until consecutive zero readings were repeated.

2.7.2 The load was raised to 20,000 pounds and the readings on all gages recorded. This procedure took about 25 minutes.

FIGURE VII

Switching Unit

FIGURE VIII

Testing Machine Control Panel

2.7.3 Readings were repeated at loads of 40,000, 60,000, 80,000, 100,000, 120,000, and 140,000 pounds.

2.7.4 The load was slowly increased until the sample fractured. The following visual observations were noted during this test:

2.7.5 At 155,000 pounds load the sample began to creep noticeably and it was no longer possible to take a set of strain gage readings.

2.7.6 As the load increased the horizontal portion of the pulling members bowed noticeably, the middle section of the pulling member experiencing greater deflection than the ends.

2.7.7 The transverse stiffeners bowed considerably at 196,000 pounds. The bowing was such that the edge of the stiffener welded to the plate was concave.

2.7.8 The welded edges of the longitudinal stiffeners were also bowed concavely. The free edges of the plate bowed in the opposite direction.

2.7.9 At 207,000 pounds the sample failed, the failure apparently starting at a notch located on the free edge of the plate.

2.8 Preparation and Test of Panel 2.

Panel 2 was a sample distorted by the heating process previously described. Figure X represents a contour map of the sample. Figure XI is a transverse section through the center of Panel 2.

The strain gage locations on Panel 2 were altered as a result of the experience gained in conducting the first test. The gage configuration is shown in Figures XII and XIII. The important changes are:

2.8.1 More gages were placed on both sides of the test section to obtain a better picture of the strain gradient.

2.8.2 Gages were placed on both sides of one edge of the sample to get a better picture of the edge loading.

2.8.3 Six SR-4, Type A-1 uniaxial gages were placed on the longitudinal stiffeners.

FIGURE X

CONTOUR MAP OF PANEL #2

SHOWING DEVIATION FROM PLANE PLATE

(CONCAVE ON UNSTIFFENED SIDE)

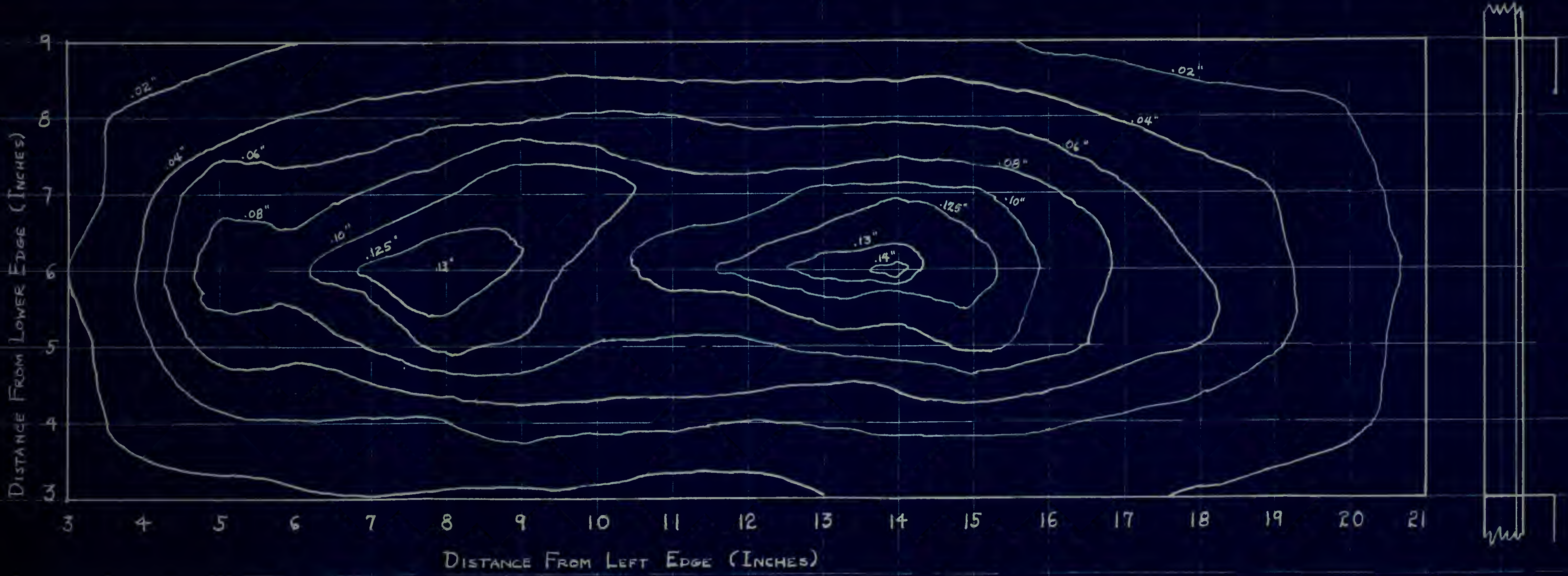
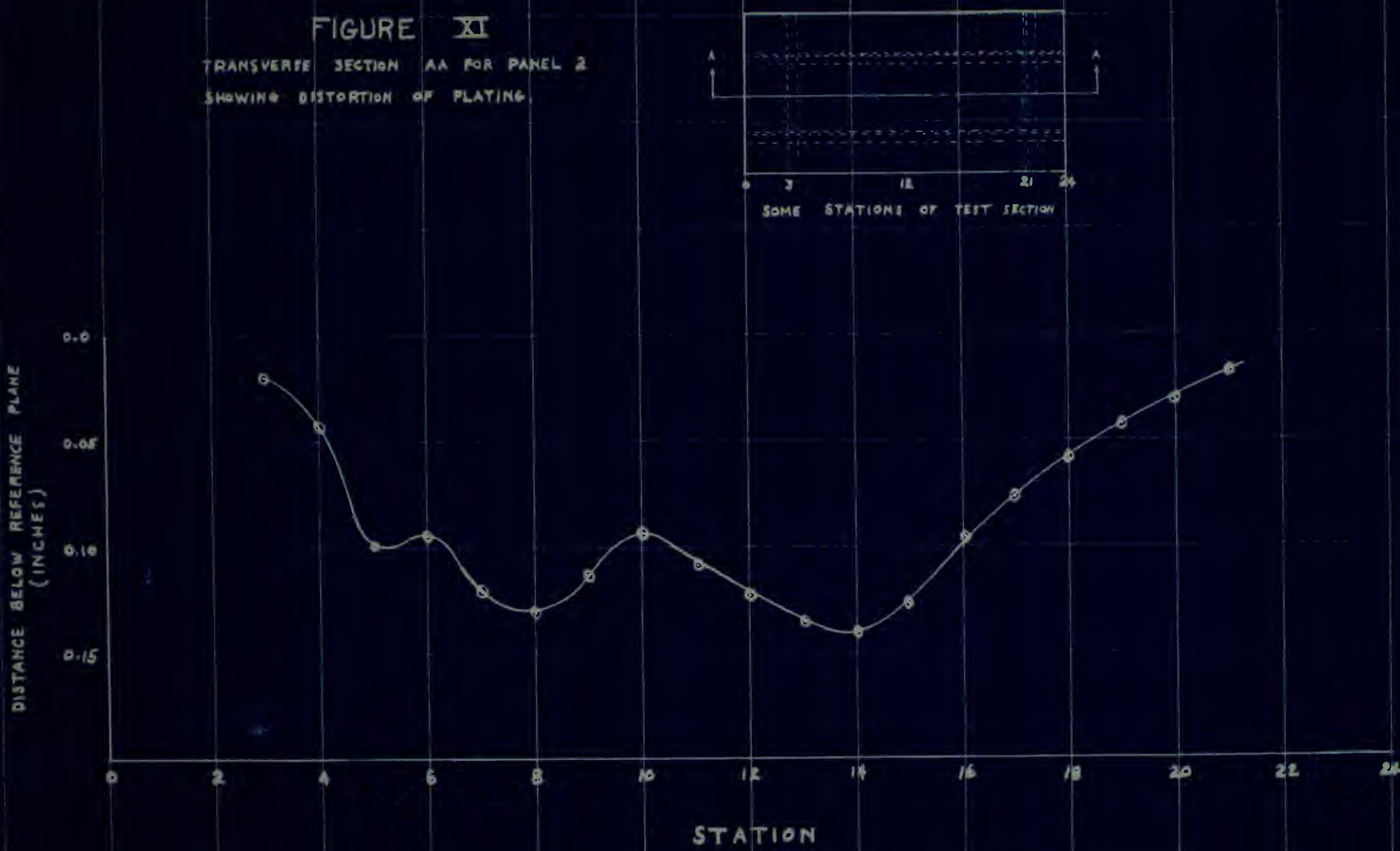


FIGURE XI

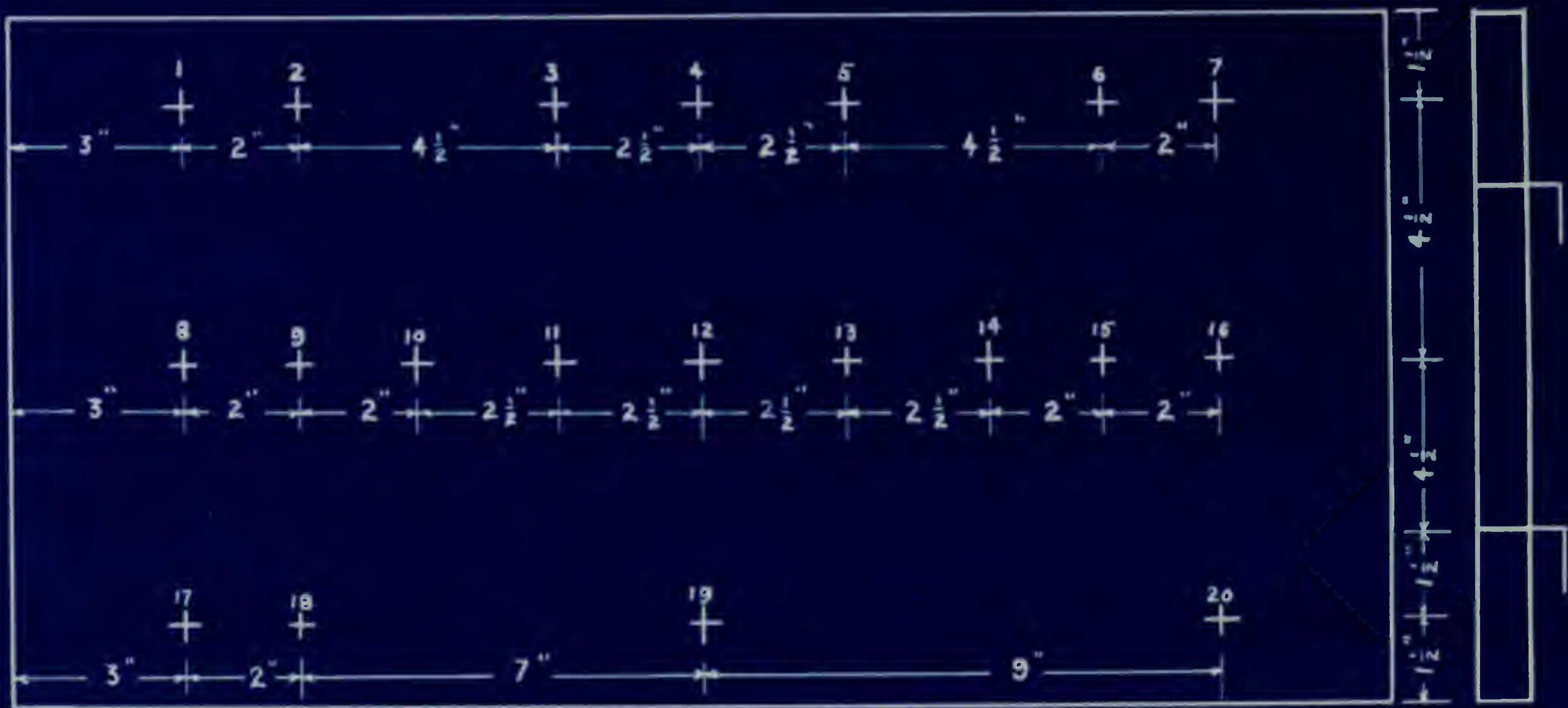
TRANSVERSE SECTION AA FOR PANEL 2
SHOWING DISTORTION OF PLATING.



REW

FIGURE XII

LOCATION OF STRAIN GAGES ON UNSTIFFENED SIDE OF PANEL TWO.



REW
4-30-53

FIGURE XIII

LOCATION OF STRAIN GAGES ON STIFFENED SIDE OF PANEL TWO LOOKING THROUGH PANEL FROM THE UNSTIFFENED SIDE. GAGES 37-42 WERE LOCATED ON THE FLANGE OF THE LONGITUDINAL STIFFENERS.

The procedure identically followed the procedure of paragraph 2.7. The following visual observations were made:

2.8.4 The specimen started to creep at about 155,000 pounds.

2.8.5 The distortion of the horizontal portion of the pulling members and transverse stiffeners was not as great as for Panel 1.

2.8.6 Failure occurred at 209,000 pounds along the weld between pulling member and plate.

2.9 Stress-Strain Curve

A stress-strain curve (Figure XIV) for the material of the plate was prepared utilizing a standard tensile specimen for 1/8 inch steel plate, as found as Figure 2 on page 376 of reference (3).

2.10 Method of Analysis

The method of analysis for both samples was identical. The object of the procedure used was to obtain a stress picture at the center of the section with a uniform tensile load on the edge. The following steps were taken:

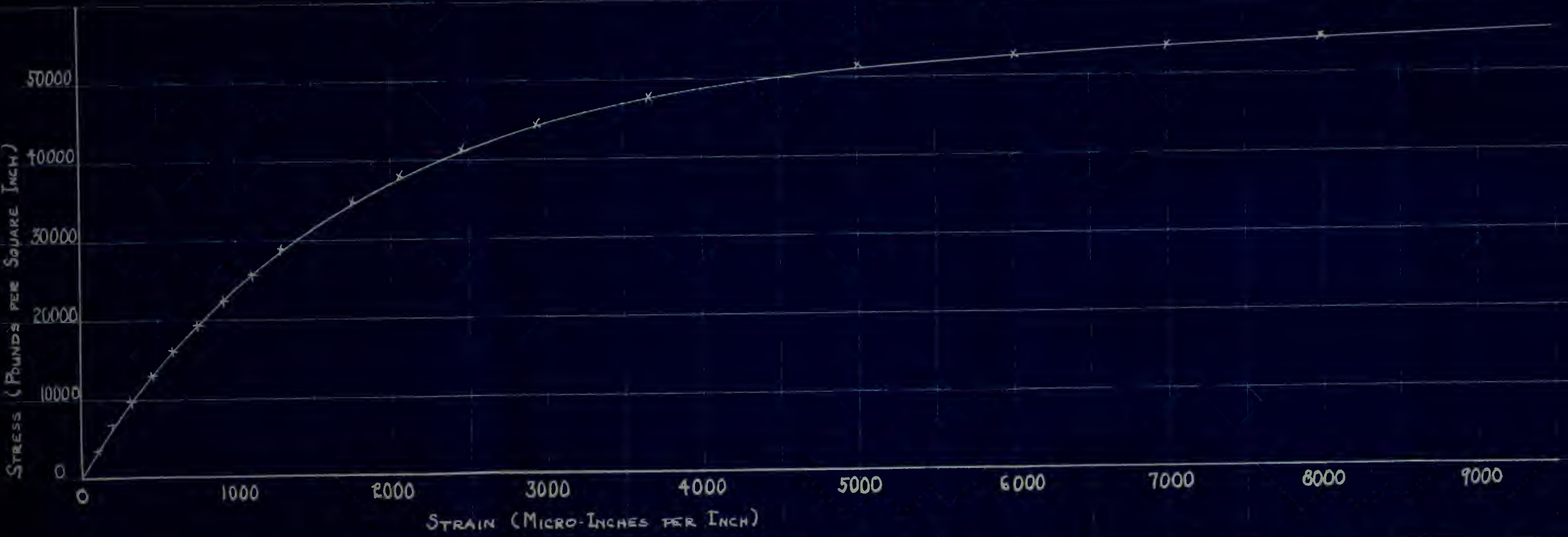
2.10.1 Rosette calculations for magnitude and direction of principal strains were obtained from the test data (see Appendix, Tables I and II). (A strain of 9460 micro-inches per inch should be added to all readings proceeded by "A"). The sequence calculations appear in Tables III through XVI of the Appendix. Results of the calculations showing magnitude and direction of principal strains are included as Tables XVII and XVIII of the Appendix.

2.10.2 A plot of principal strains versus stations was then made.

FIGURE XIV

STRESS-STRAIN CURVE FOR STEEL OF TEST PANEL

MEDIUM TENSILE STEEL MAX CARBON CONTENT 0.31%



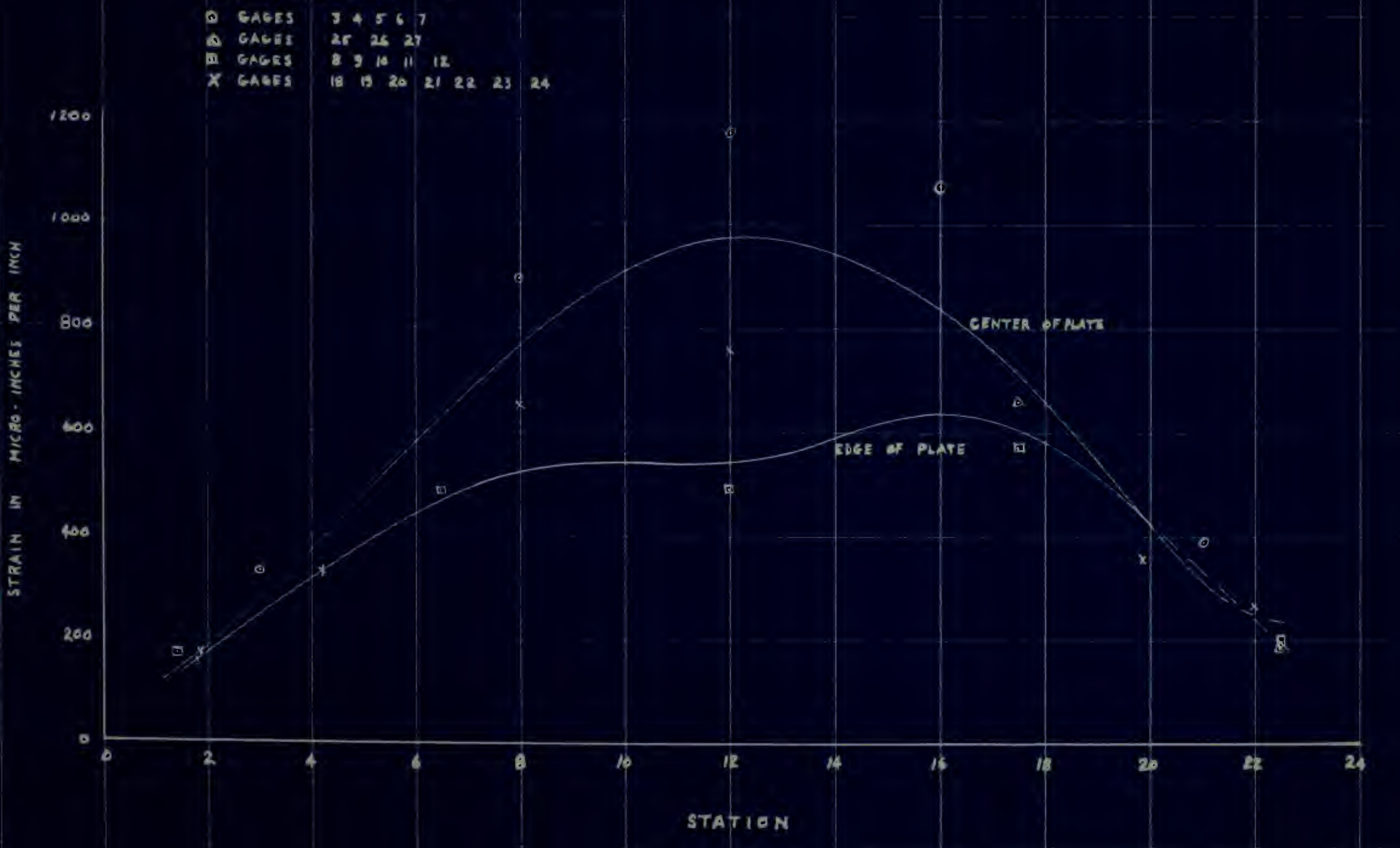
The number of a station is defined as the distance in inches from the left edge of the panel with the flanges of the transverse stiffeners pointing downward as an observer looks at and through the unstiffened side. A curve was then drawn using the arithmetic mean of strain readings on opposite sides of the panel. Figures XV and XVI represent typical curves for loads of 40,000 and 120,000 pounds on Panel 1. Figures XVII and XVIII are the curves for the same loads on Panel 2.

2.10.3 Next the cross-curves (Figures XIX - XXXII) for seven stations on each plate were prepared. The points for a particular station were obtained by plotting mean strain at that station versus the load at which that strain occurred. The strains used were the values read from the plots of paragraph 2.10.2. Two curves for each station were then drawn; one depicting edge strain versus load, the other center of plate strain versus load. These curves were faired in to minimize errors made in the construction of the curves of paragraph 2.10.2.

2.10.4 It was now possible to construct the stress and strain pattern at the center of the plate for a uniform tensile loading on the edge. Uniform strains of 500, 1000, 1500, and 2000 micro-inches per inch were selected. For each station the corresponding center of plate strain was plotted against station number. The resulting curve represented center of plate strain for uniform strain at the edge. The stress pattern was then plotted from the stress-strain relationship of Figure XIV. The uniform tension curves are included as Figures XXXIII - XXXVI for Panel 1 and Figures XXXVII - XL for Panel 2.

FIGURE XV

STRAIN VERSUS LOCATION FOR PANEL 1 AT 40,000 POUND LOAD



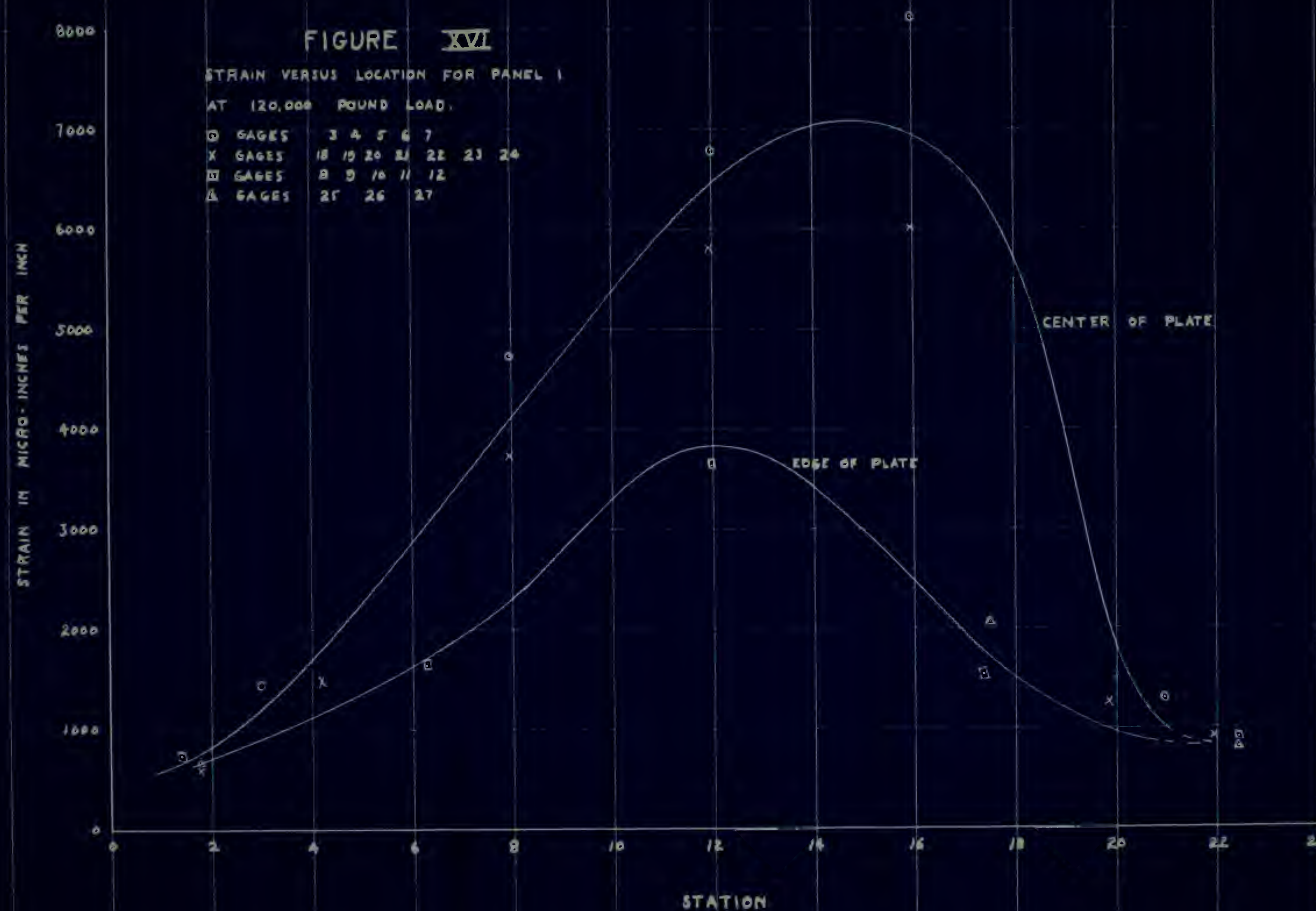
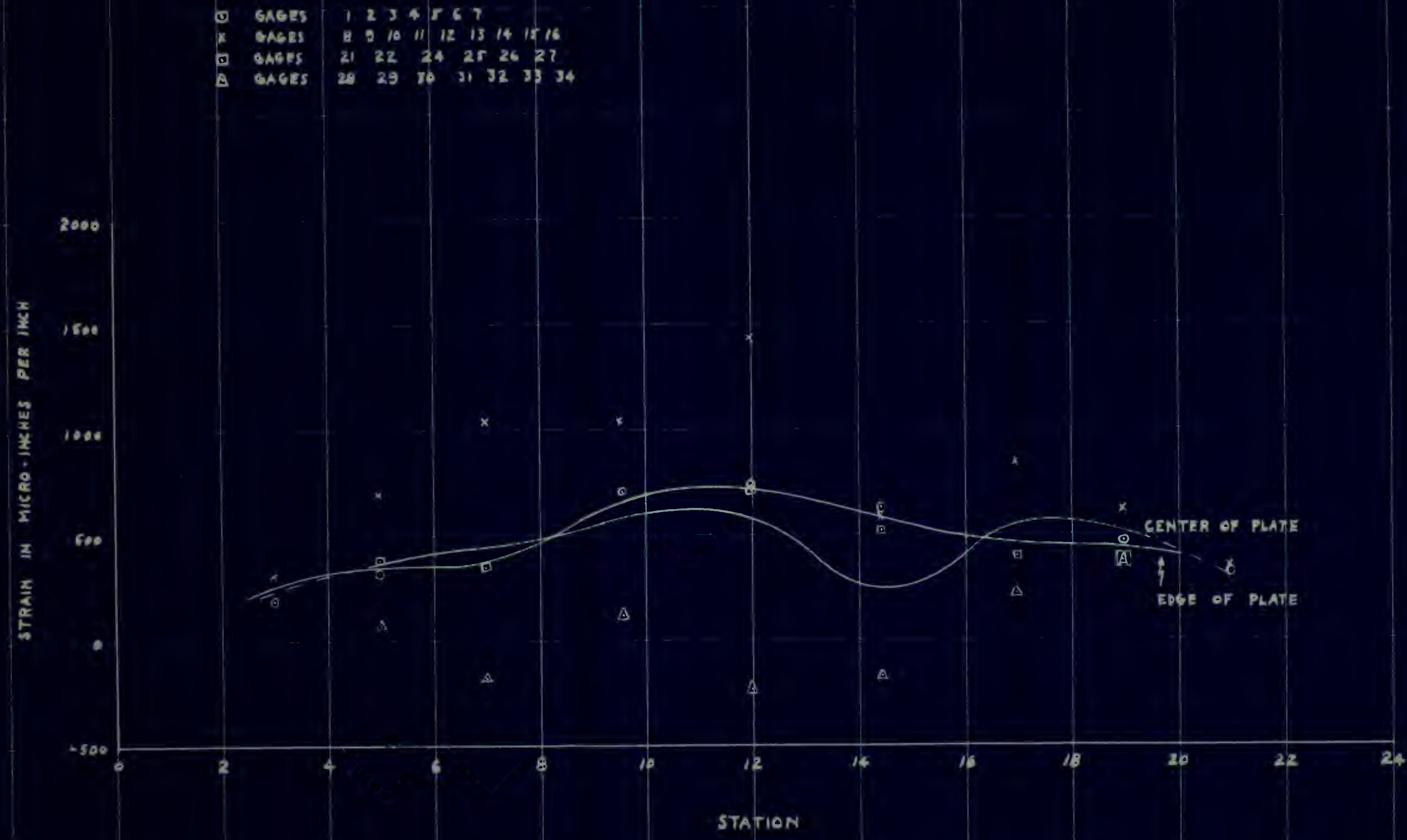


FIGURE XVI
STRAIN VERSUS LOCATION FOR PANEL 1
AT 120,000 POUND LOAD.
GAGES 3 4 5 6 7
X GAGES 18 19 20 21 22 23 24
GAGES 8 9 10 11 12
GAGES 25 26 27
CENTER OF PLATE
EDGE OF PLATE
STRAIN IN MICRO-INCHES PER INCH
STATION
0
1000
2000
3000
4000
5000
6000
7000
8000
0
2
4
6
8
10
12
14
16
18
20
22
24

FIGURE XVII

STRAIN VERSUS LOCATION FOR PANEL 2 AT 40,000 POUND LOAD.



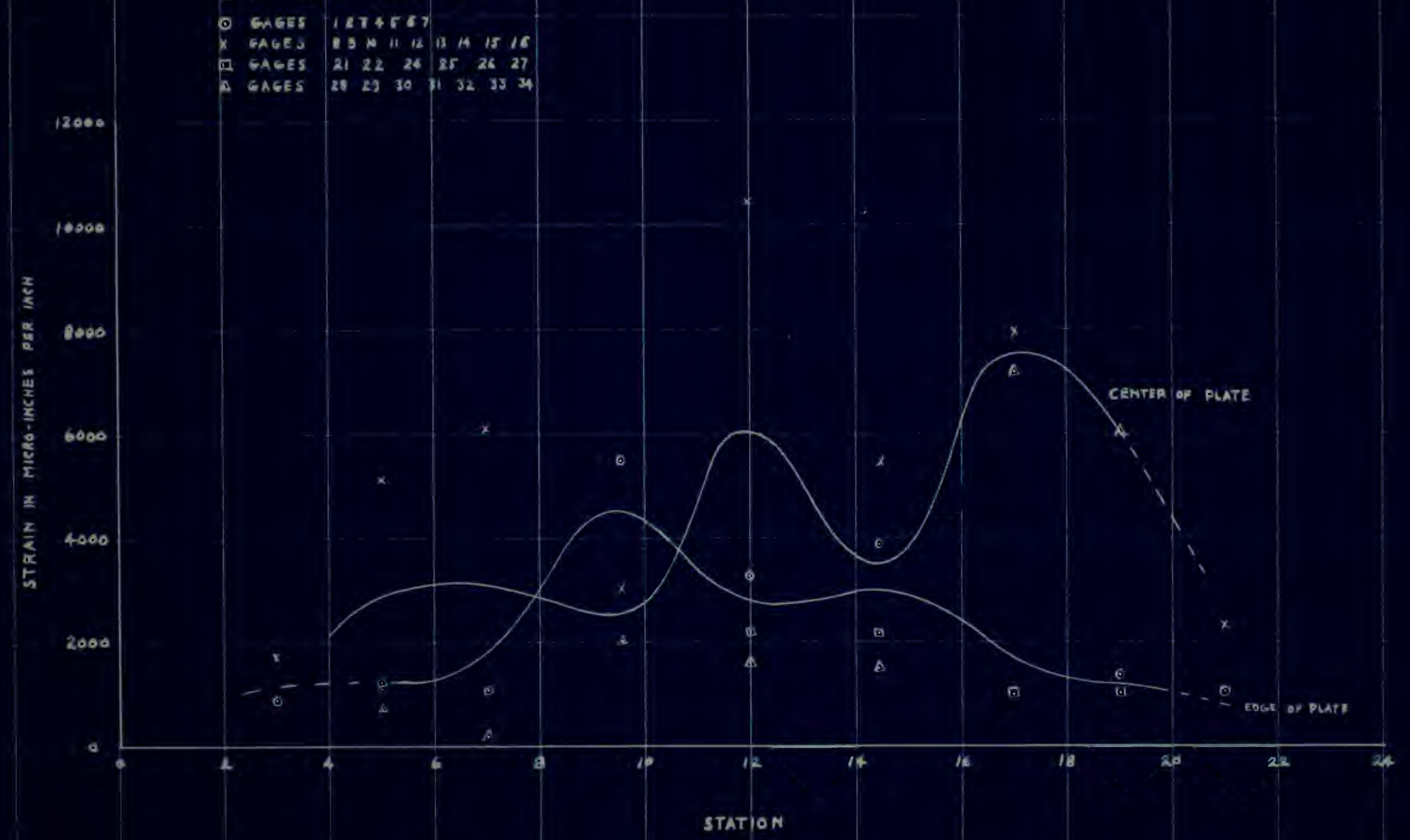


FIGURE XVIII

STRAIN VERSUS LOCATION FOR PANEL 2 AT 120,000 POUND LOAD.

FIGURE XIX
CROSS-CURVE AT STATION 4
FOR PANEL 1

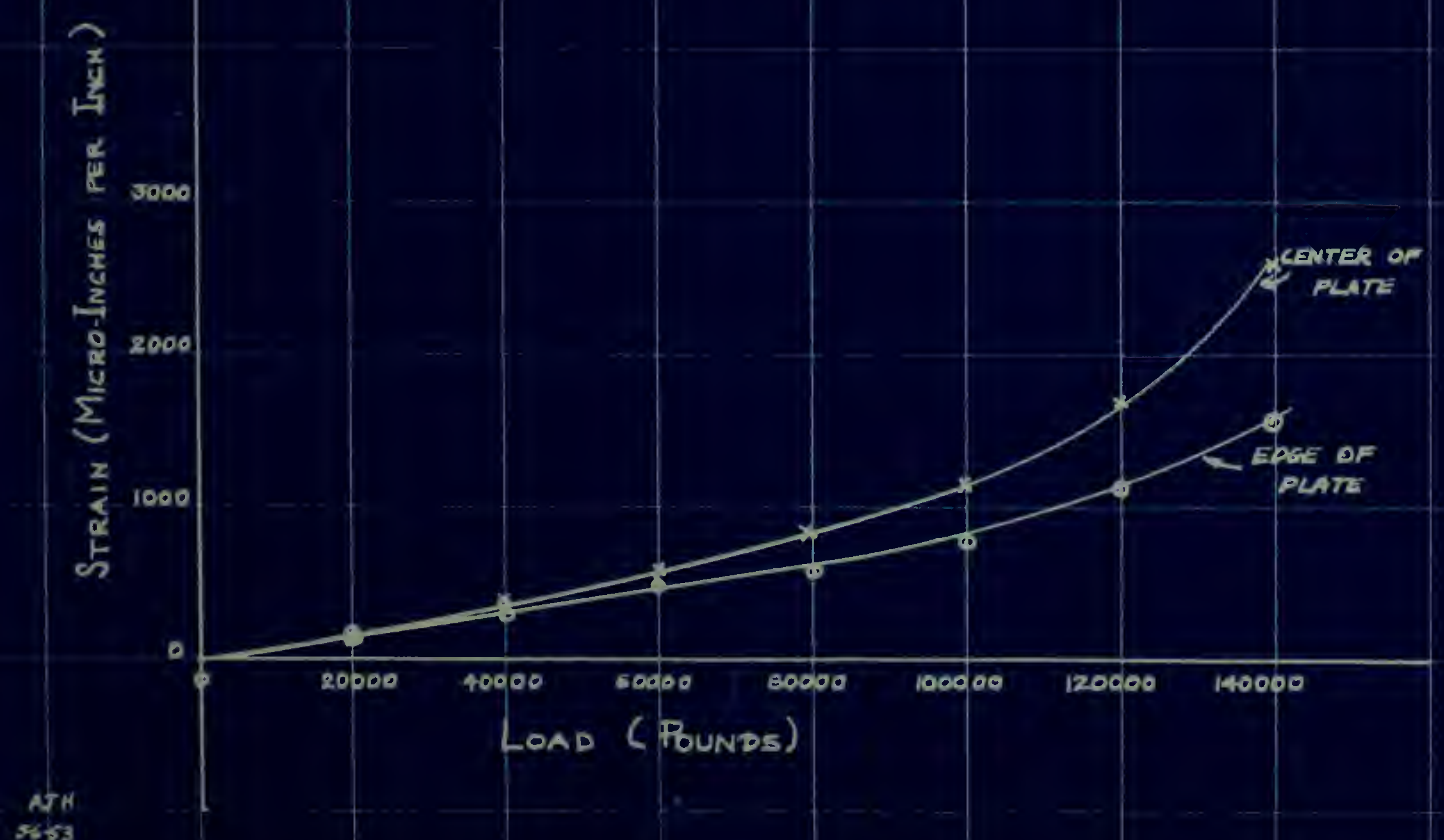


FIGURE XI

CROSS-CURVE AT STATION 6

FOR PANEL 1

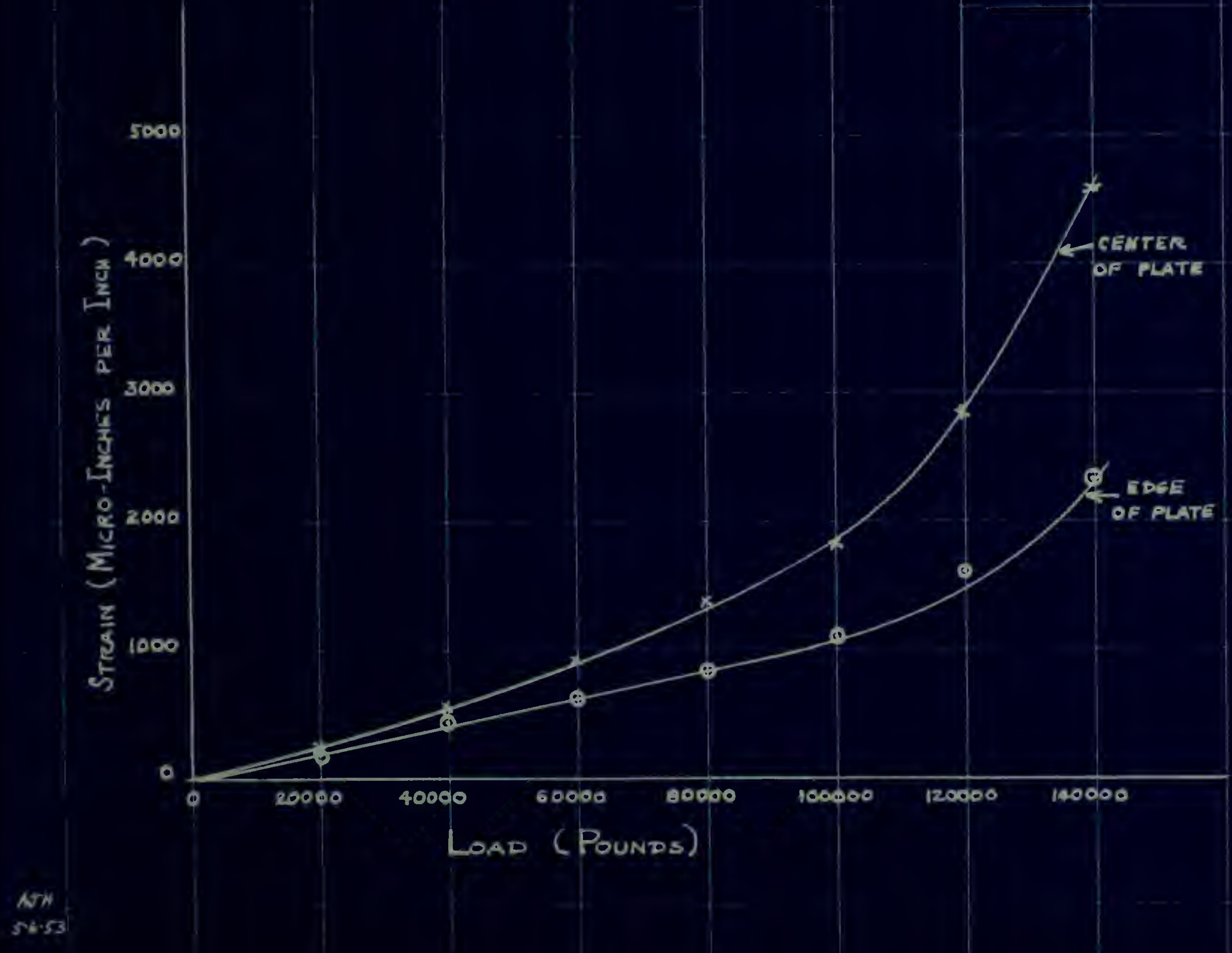
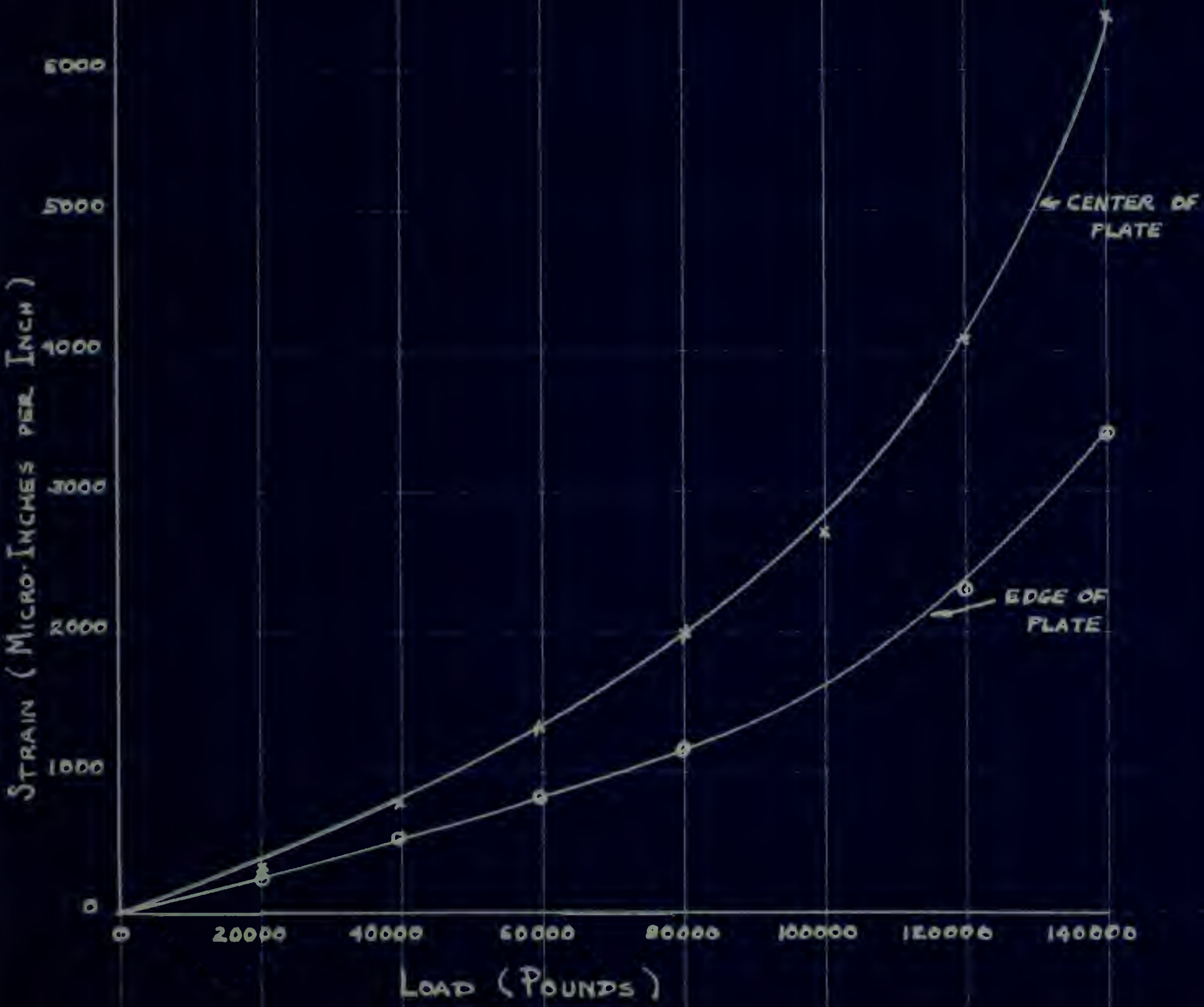


FIGURE XXI
CROSS-CURVE AT STATION 8
FOR PANEL 1



AJH
5-6-53

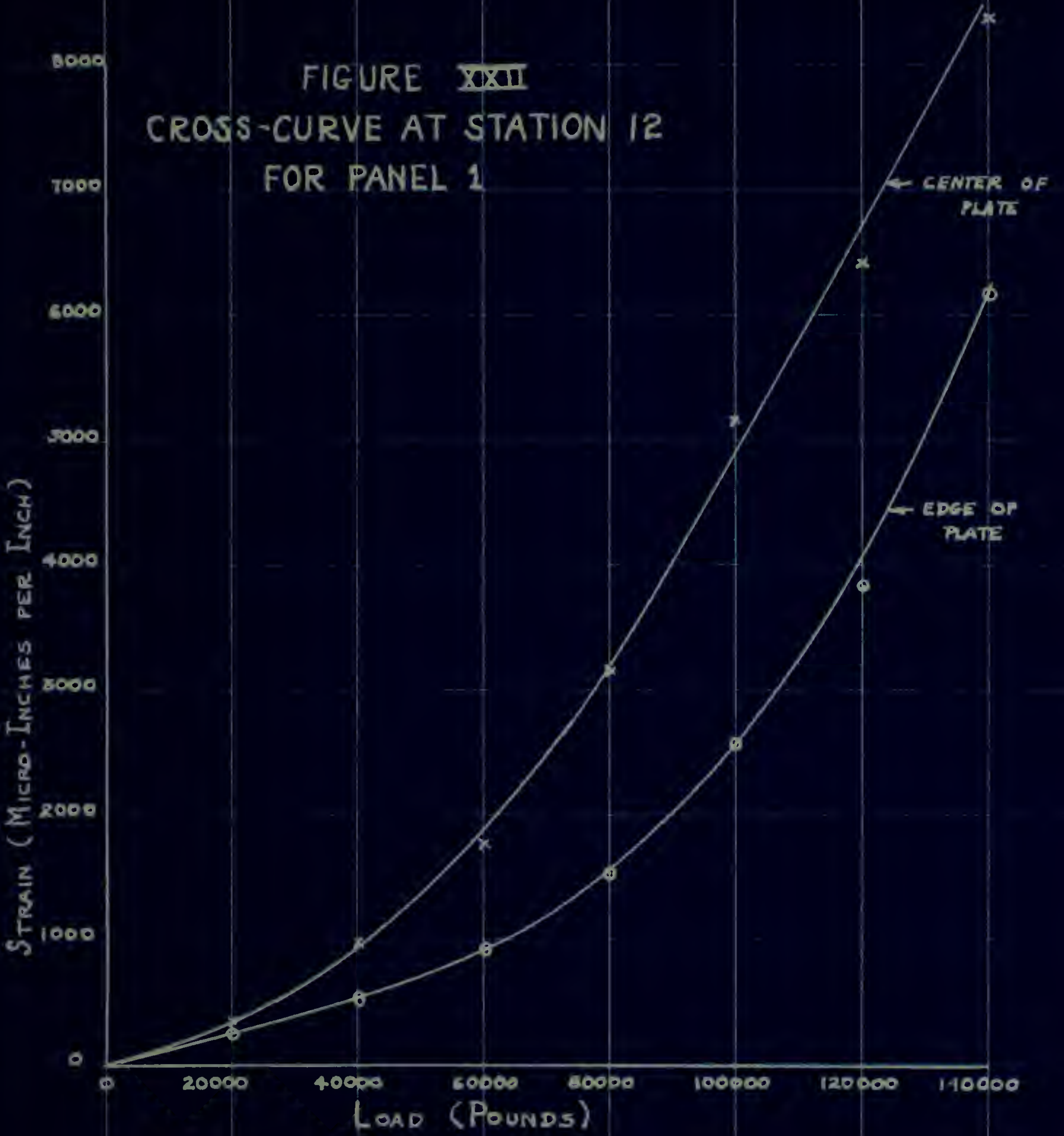


FIGURE XXII
CROSS-CURVE AT STATION 12
FOR PANEL 1

AJH
5-6-53

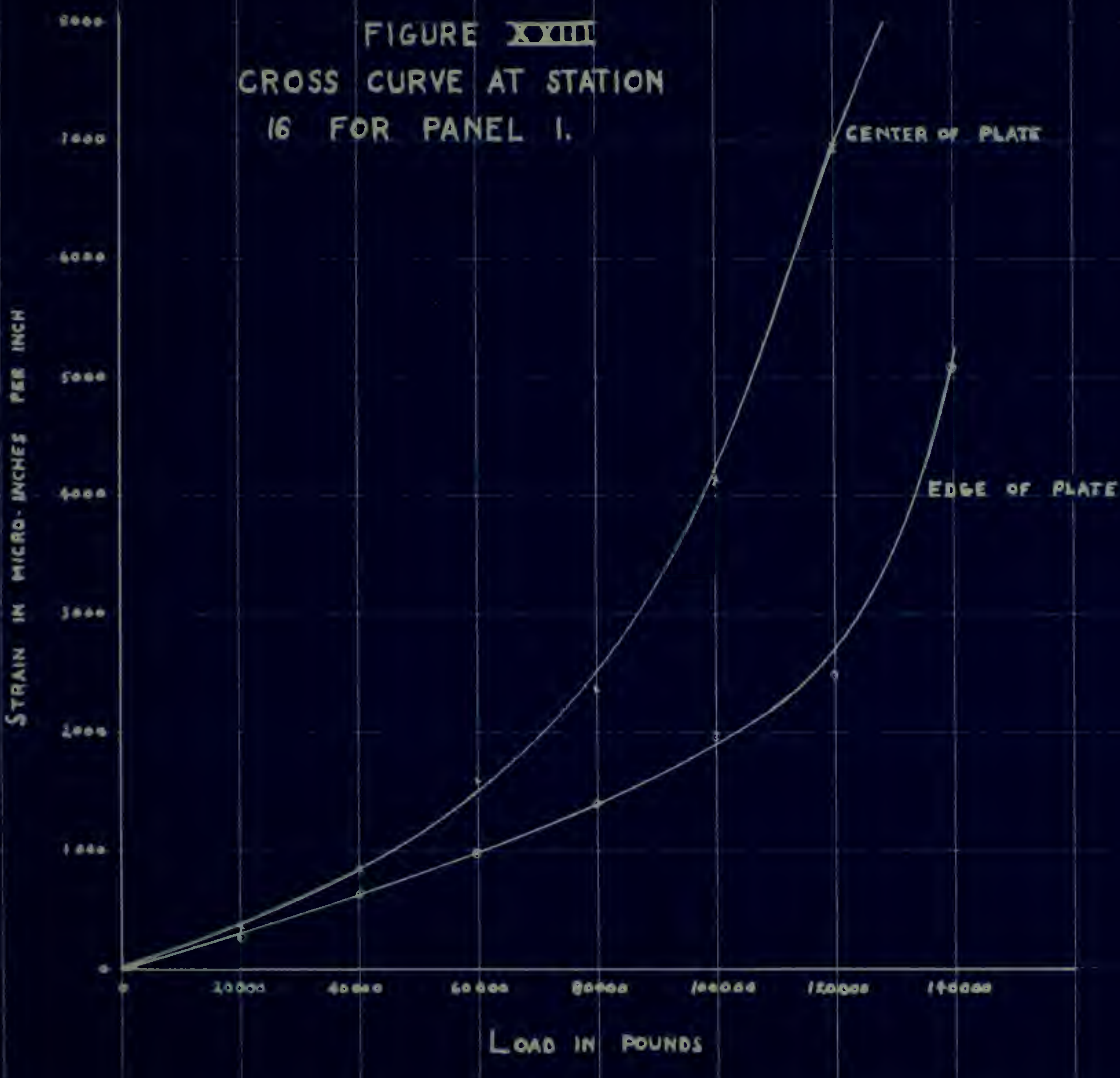


FIGURE XVIII
CROSS CURVE AT STATION
16 FOR PANEL 1.

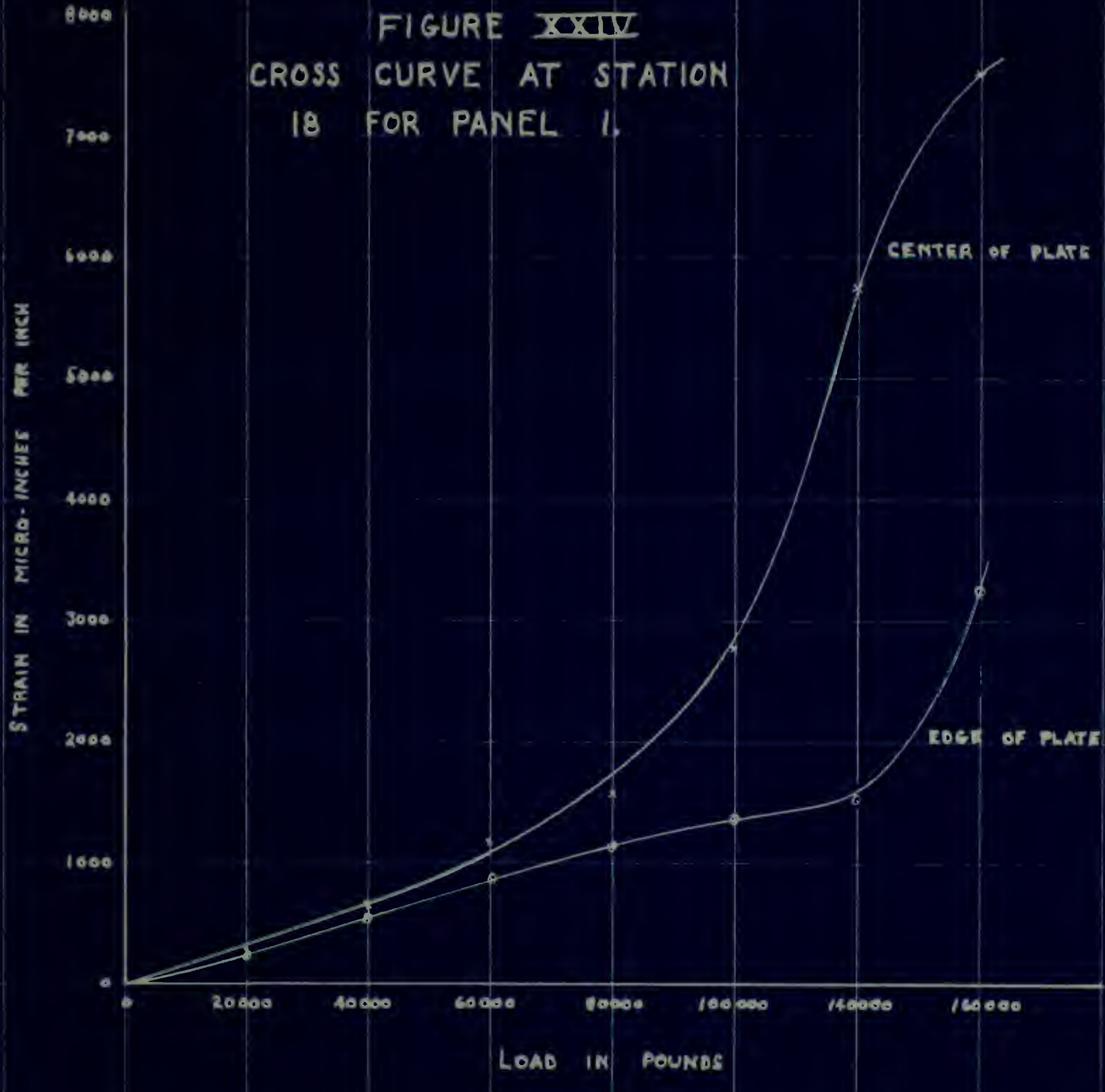
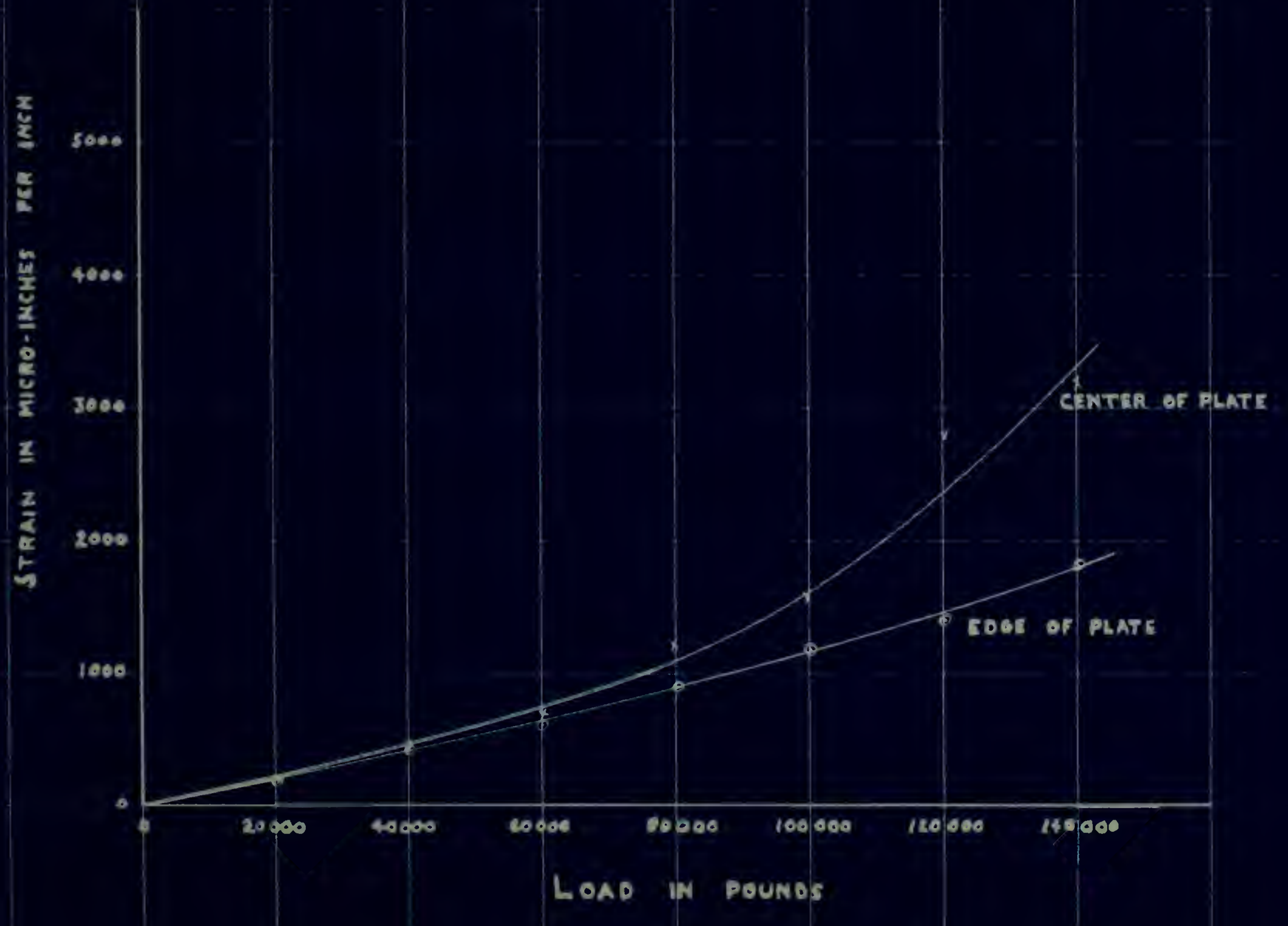


FIGURE XXIV
CROSS CURVE AT STATION
18 FOR PANEL 1.
CENTER OF PLATE
EDGE OF PLATE
STRAIN IN MICRO-INCHES PER INCH
LOAD IN POUNDS
8000
7000
6000
5000
4000
3000
2000
1000
0
20000
40000
60000
80000
100000
140000
160000

FIGURE XXV

CROSS CURVE AT STATION 20 FOR PANEL I.



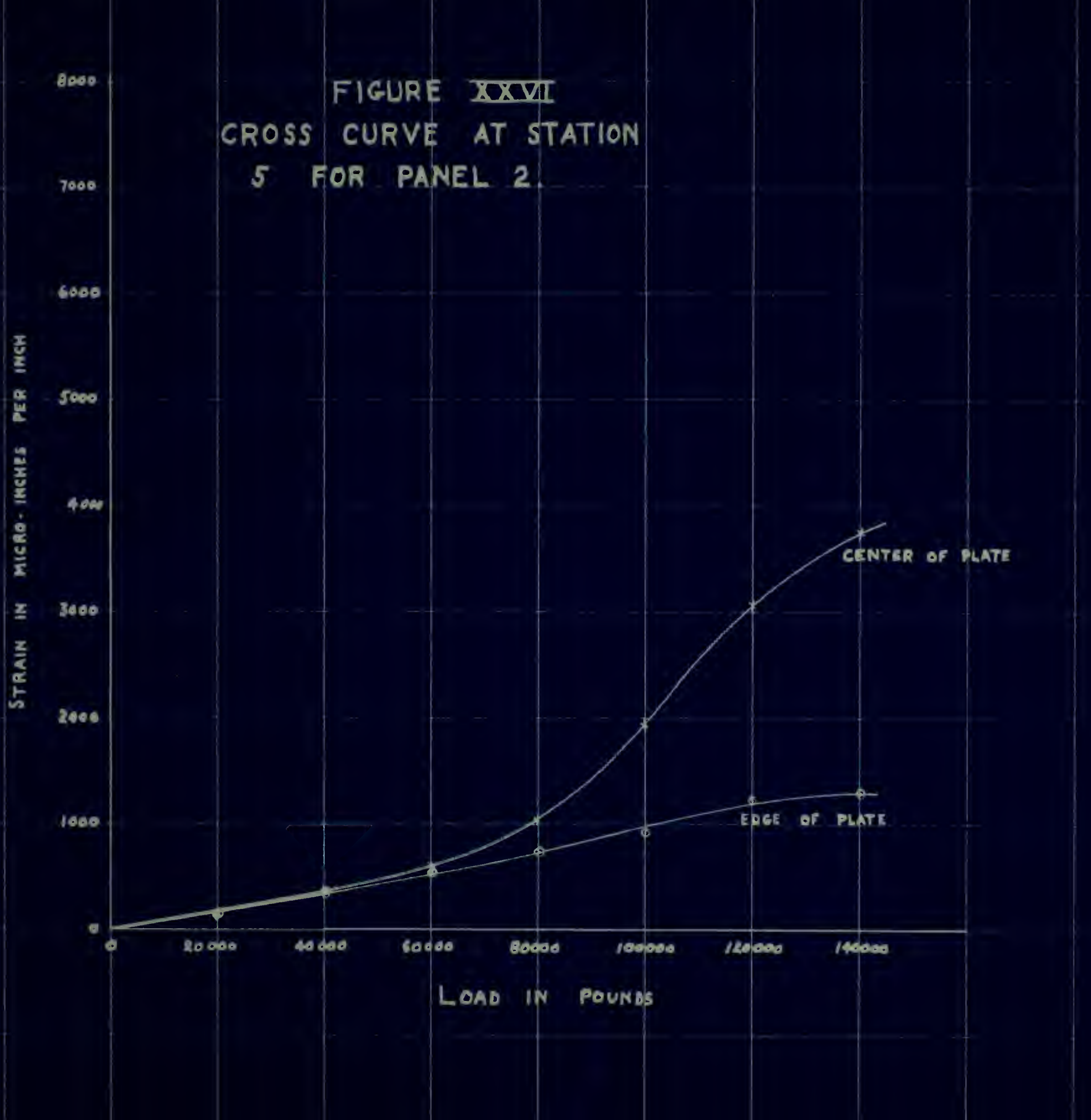


FIGURE XXVI
CROSS CURVE AT STATION
5 FOR PANEL 2.
STRAIN IN MICRO-INCHES PER INCH
8000
7000
6000
5000
4000
3000
2000
1000
0
CENTER OF PLATE
EDGE OF PLATE
0
20000
40000
60000
80000
100000
120000
140000
LOAD IN POUNDS

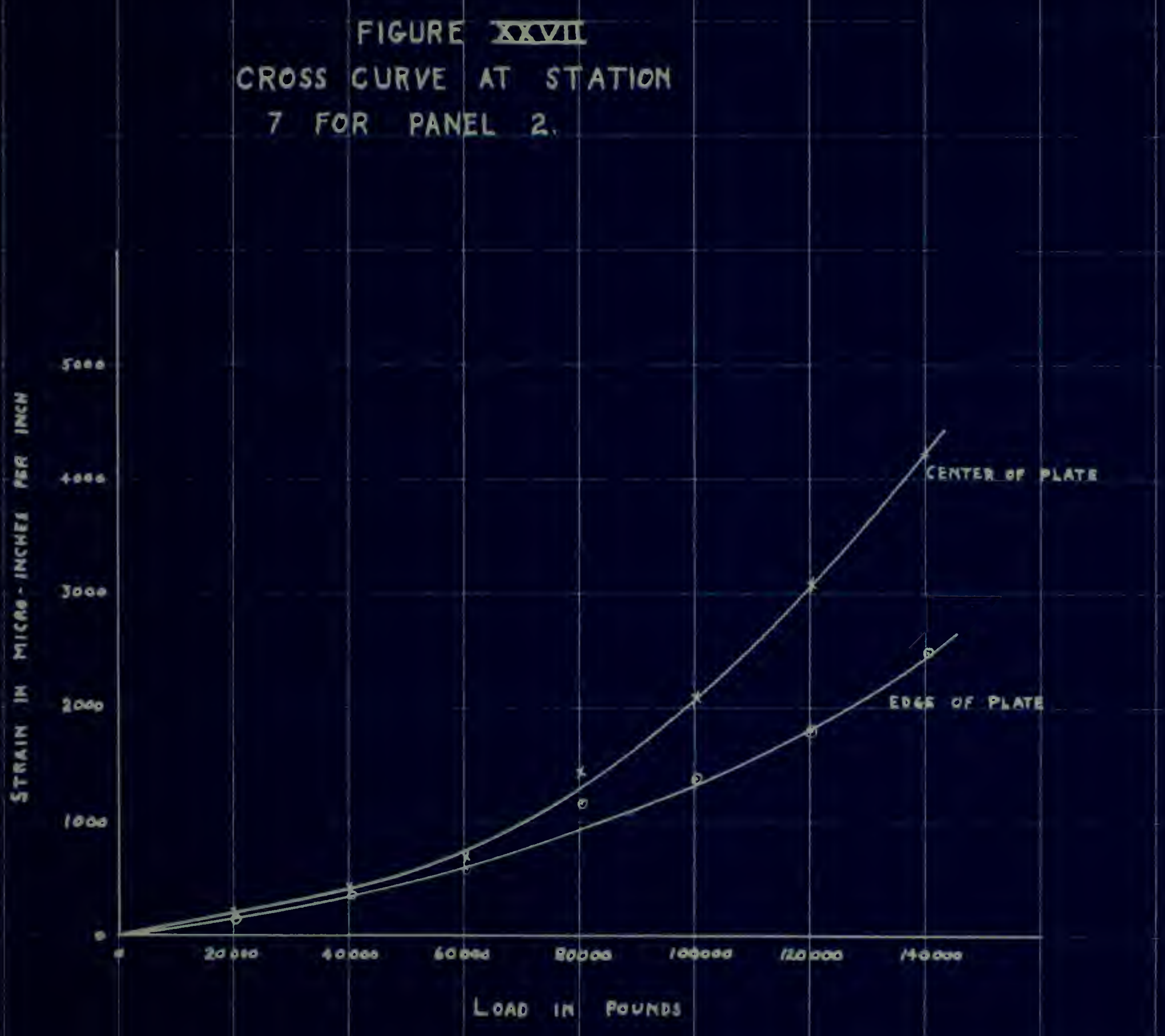


FIGURE XXVII
CROSS CURVE AT STATION
7 FOR PANEL 2.
STRAIN IN MICRO-INCHES PER INCH
5000
4000
3000
2000
1000
0
0
20000
40000
60000
80000
100000
120000
140000
LOAD IN POUNDS
CENTER OF PLATE
EDGE OF PLATE

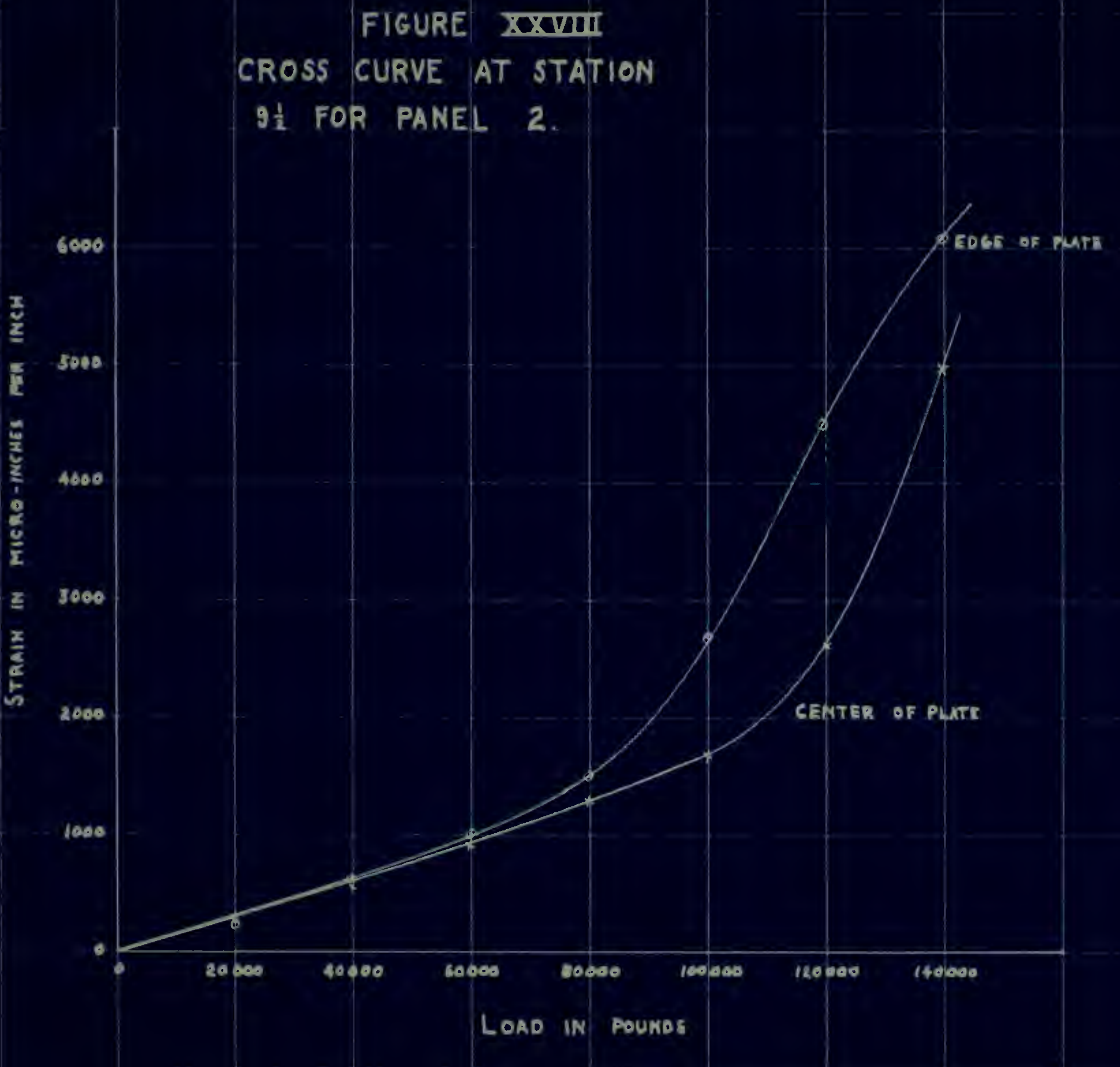


FIGURE XXVIII
CROSS CURVE AT STATION
9½ FOR PANEL 2.
STRAIN IN MICRO-INCHES PER INCH
LOAD IN POUNDS
EDGE OF PLATE
CENTER OF PLATE
0
1000
2000
3000
4000
5000
6000
20000
40000
60000
80000
100000
120000
140000

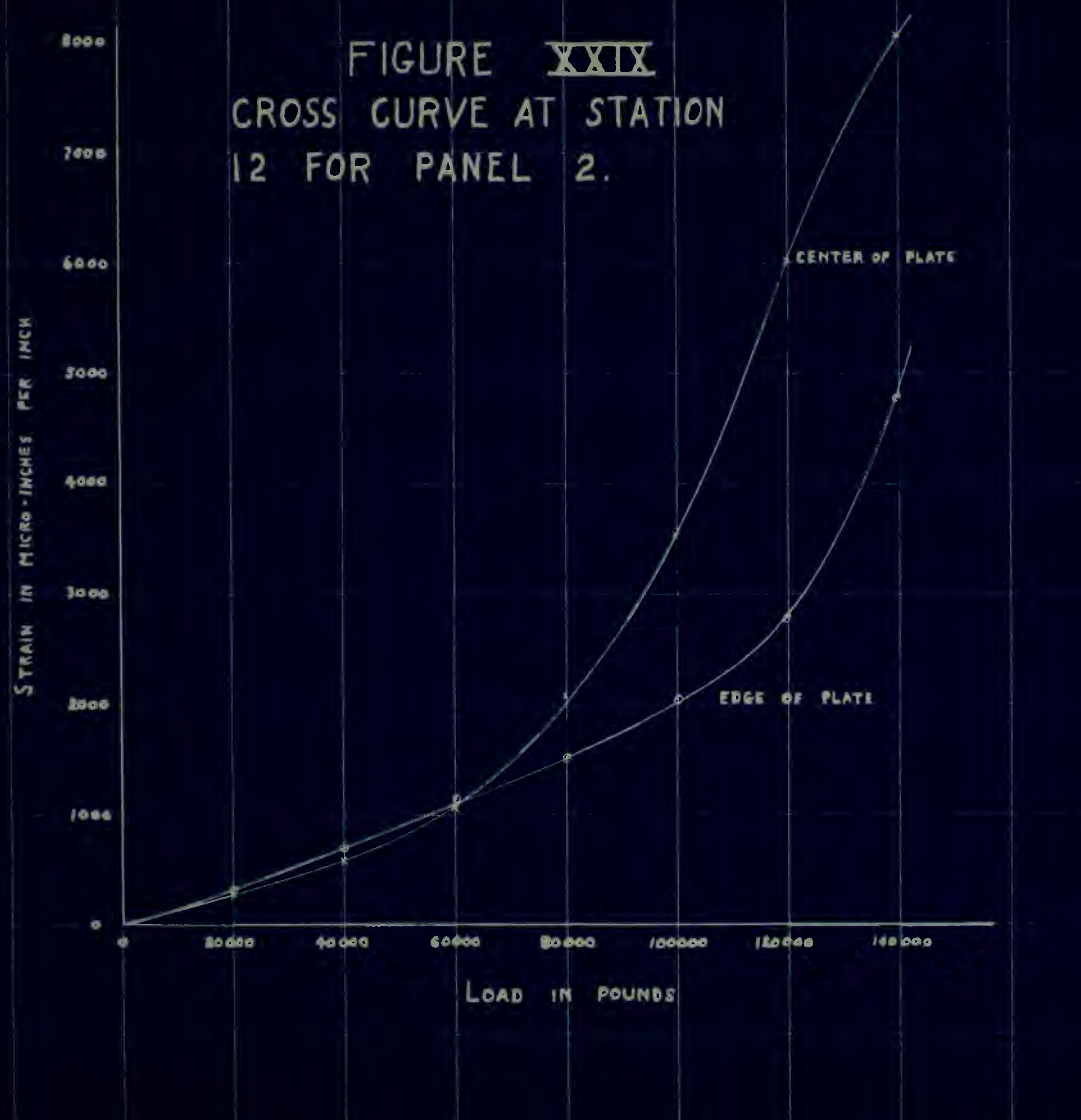


FIGURE XXIX
CROSS CURVE AT STATION
12 FOR PANEL 2.
CENTER OF PLATE
EDGE OF PLATE
STRAIN IN MICRO-INCHES PER INCH
LOAD IN POUNDS
8000
7000
6000
5000
4000
3000
2000
1000
0
20000
40000
60000
80000
100000
120000
140000

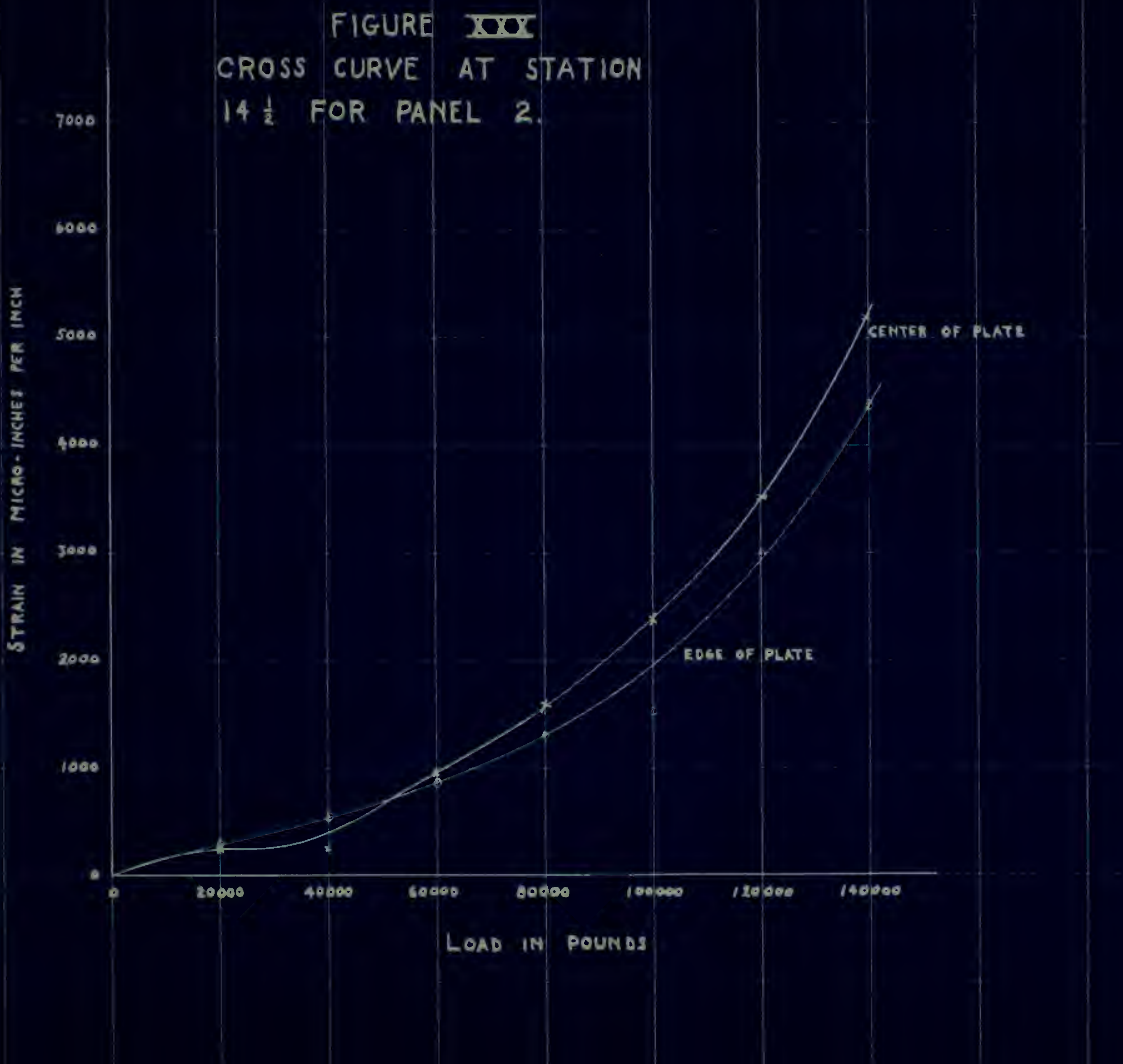


FIGURE XXX
CROSS CURVE AT STATION
14 ½ FOR PANEL 2.
STRAIN IN MICRO-INCHES PER INCH
7000
6000
5000
4000
3000
2000
1000
0
CENTER OF PLATE
EDGE OF PLATE
0
20000
40000
60000
80000
100000
120000
140000
LOAD IN POUNDS

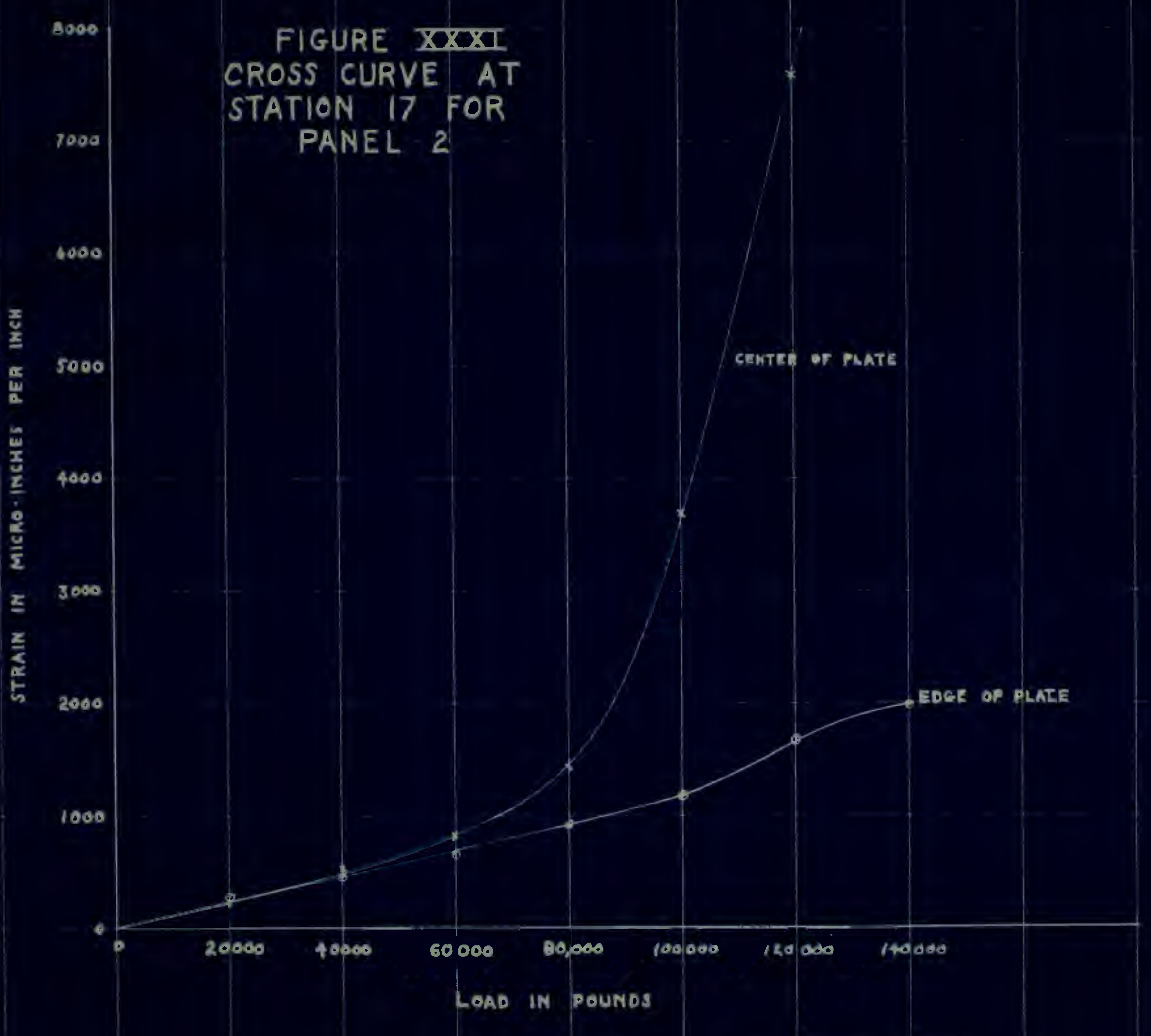


FIGURE XXXI
CROSS CURVE AT
STATION 17 FOR
PANEL 2
STRAIN IN MICRO-INCHES PER INCH
8000
7000
6000
5000
4000
3000
2000
1000
0
CENTER OF PLATE
EDGE OF PLATE
0
20000
40000
60 000
80,000
100,000
120,000
140000
LOAD IN POUNDS

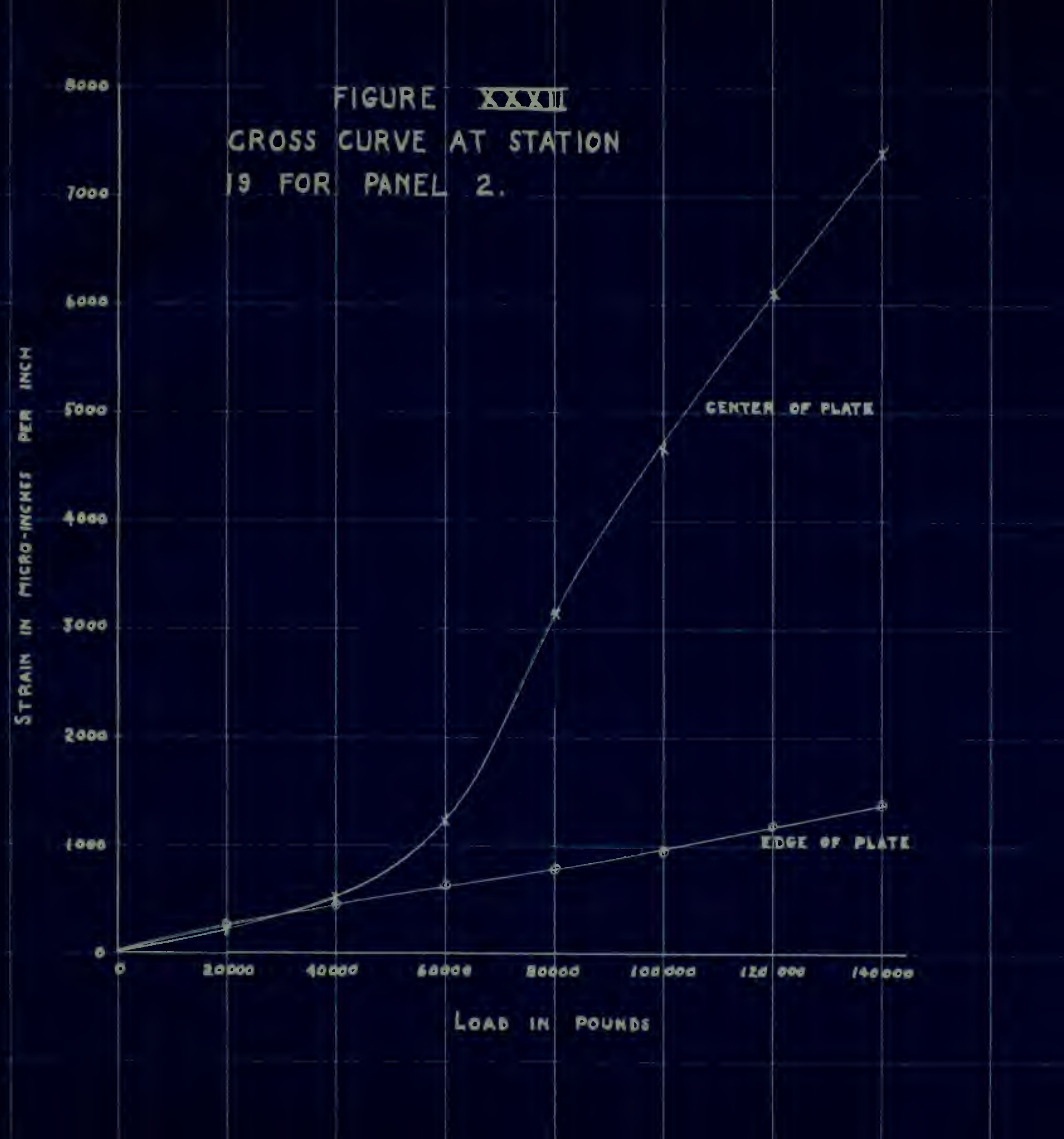
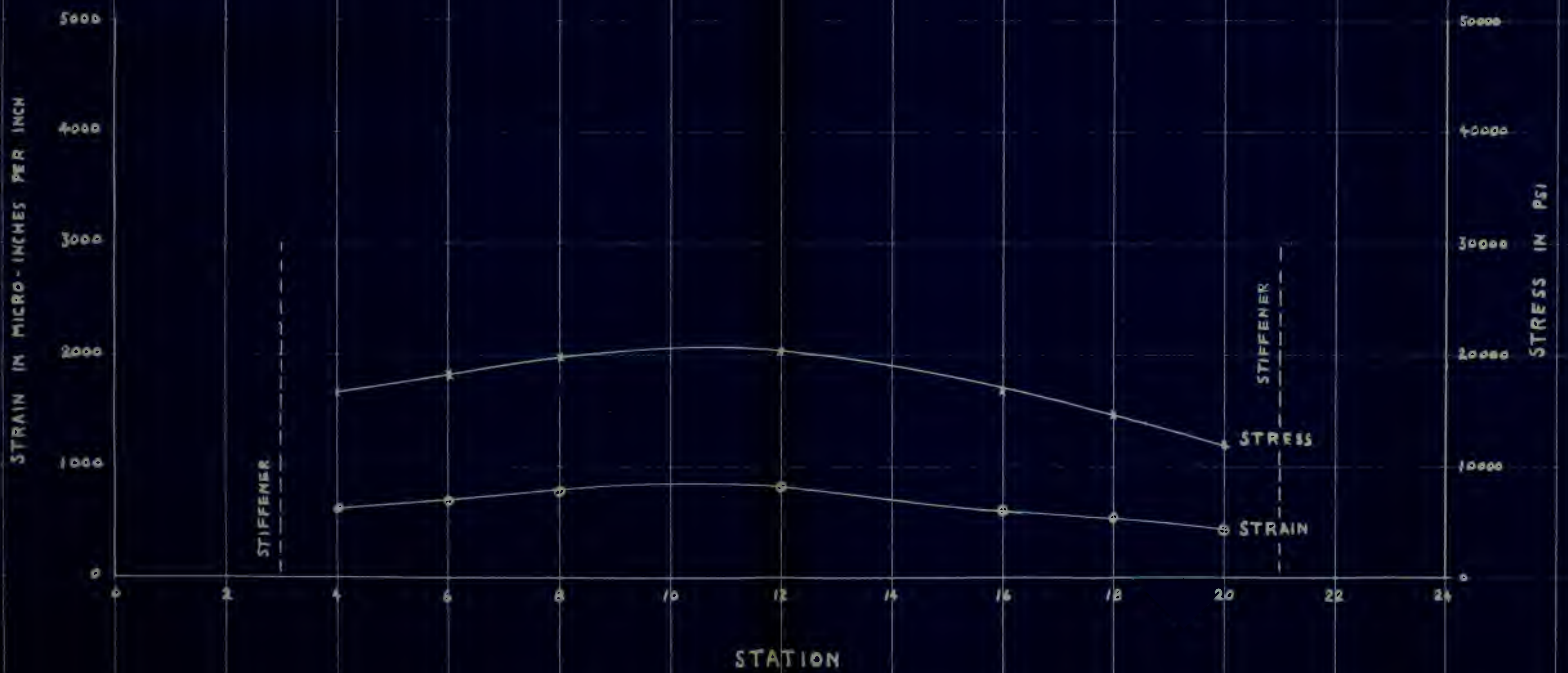


FIGURE XXXII
CROSS CURVE AT STATION
19 FOR PANEL 2.
CENTER OF PLATE
EDGE OF PLATE
STRAIN IN MICRO-INCHES PER INCH
LOAD IN POUNDS
0
1000
2000
3000
4000
5000
6000
7000
8000
20000
40000
60000
80000
100000
120000
140000

S.E.W.
2-8-53

FIGURE XXXIII

PANEL 1 WITH UNIFORM STRAIN OF 500 MICRO-INCHES PER INCH IN EDGE (14,000 PSI) SHOWING MID-PANEL MID-THICKNESS STRESSES AND STRAINS.



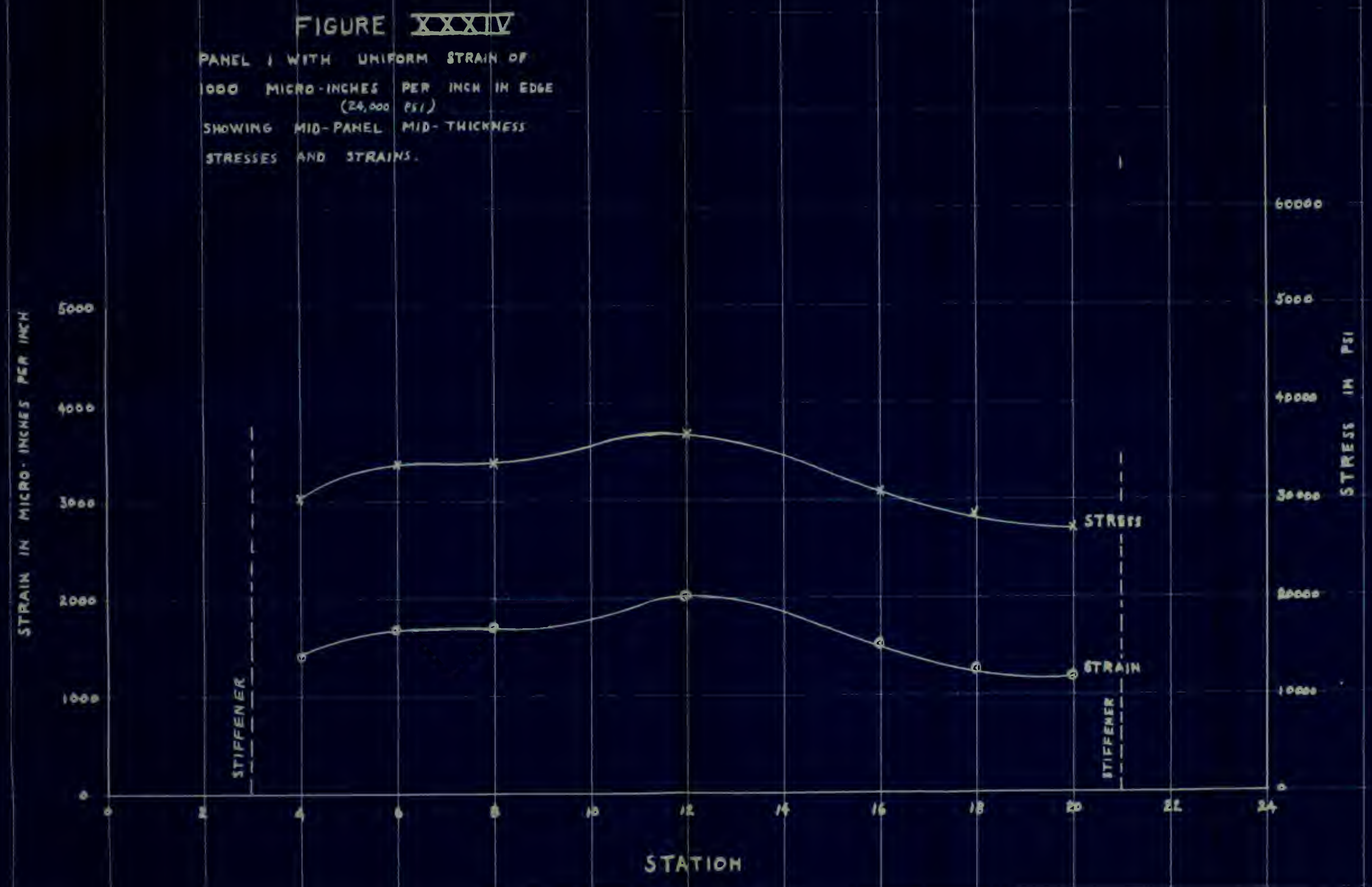


FIGURE XXXIV
PANEL 1 WITH UNIFORM STRAIN OF
1000 MICRO-INCHES PER INCH IN EDGE
(24,000 PSI)
SHOWING MID-PANEL MID-THICKNESS
STRESSES AND STRAINS.
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STIFFENER
STIFFENER
STRESS
STRAIN
STATION
0
1000
2000
3000
4000
5000
10000
20000
30000
40000
50000
60000
0
2
4
6
8
10
12
14
16
18
20
22
24

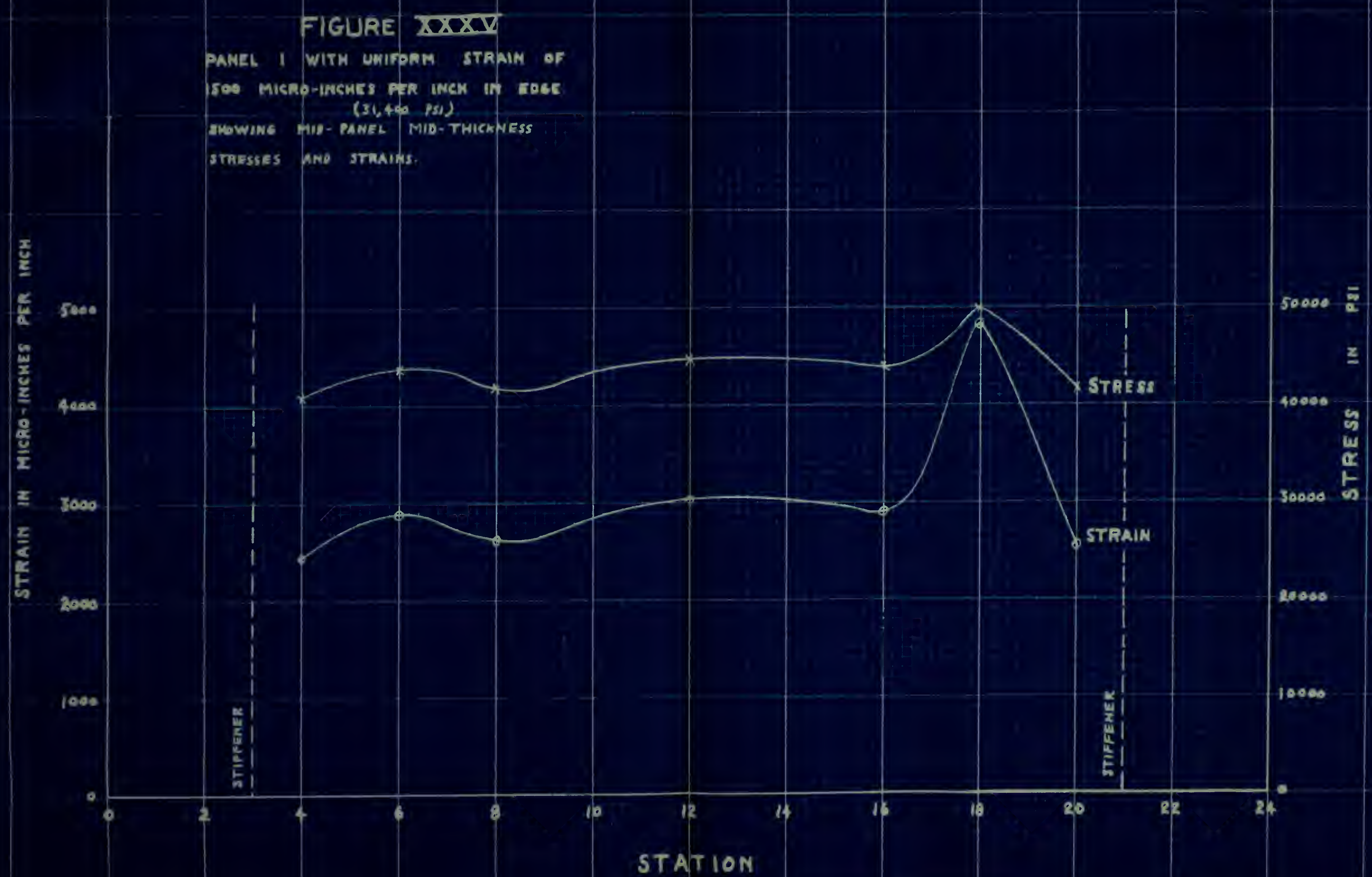
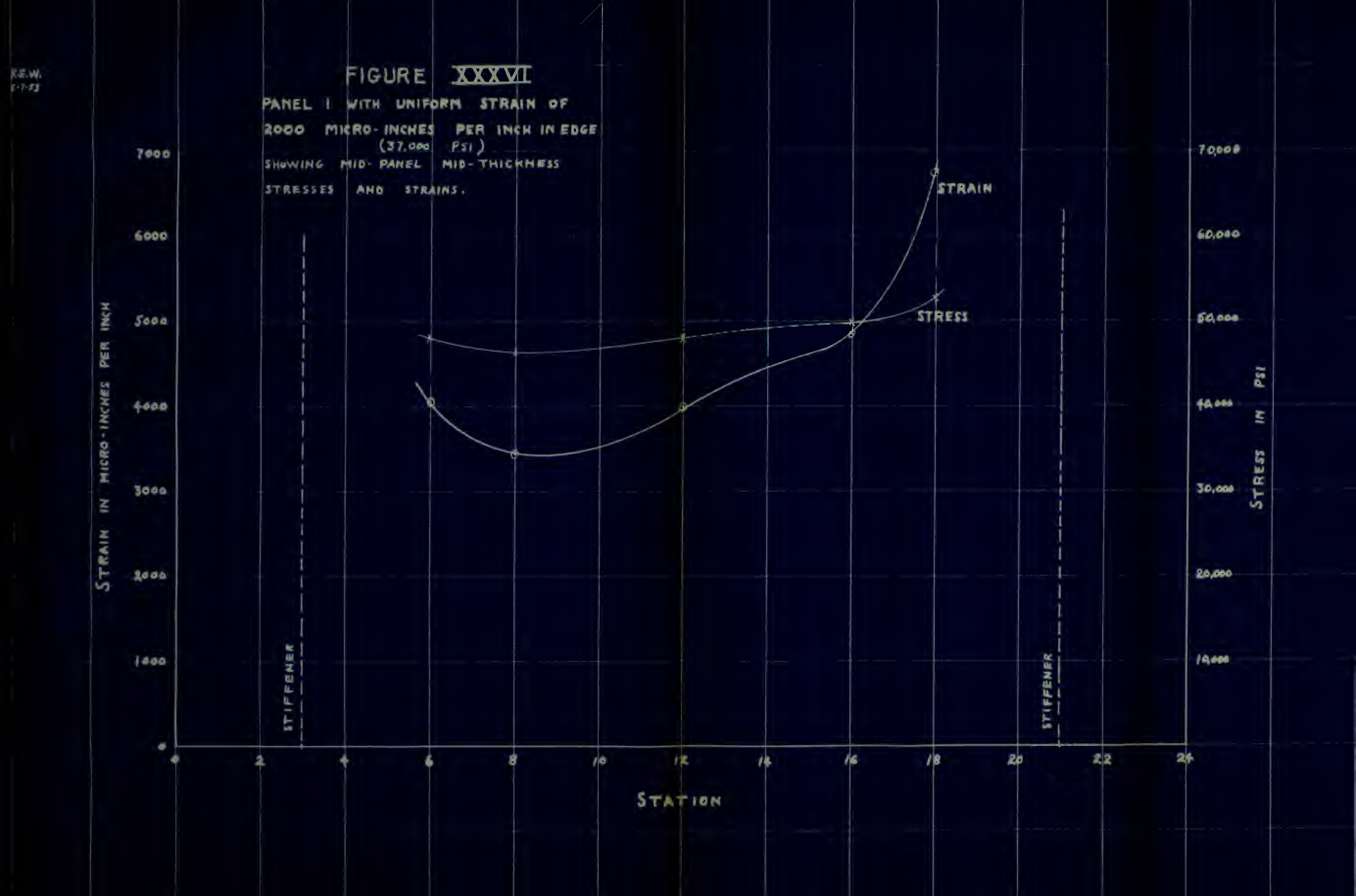


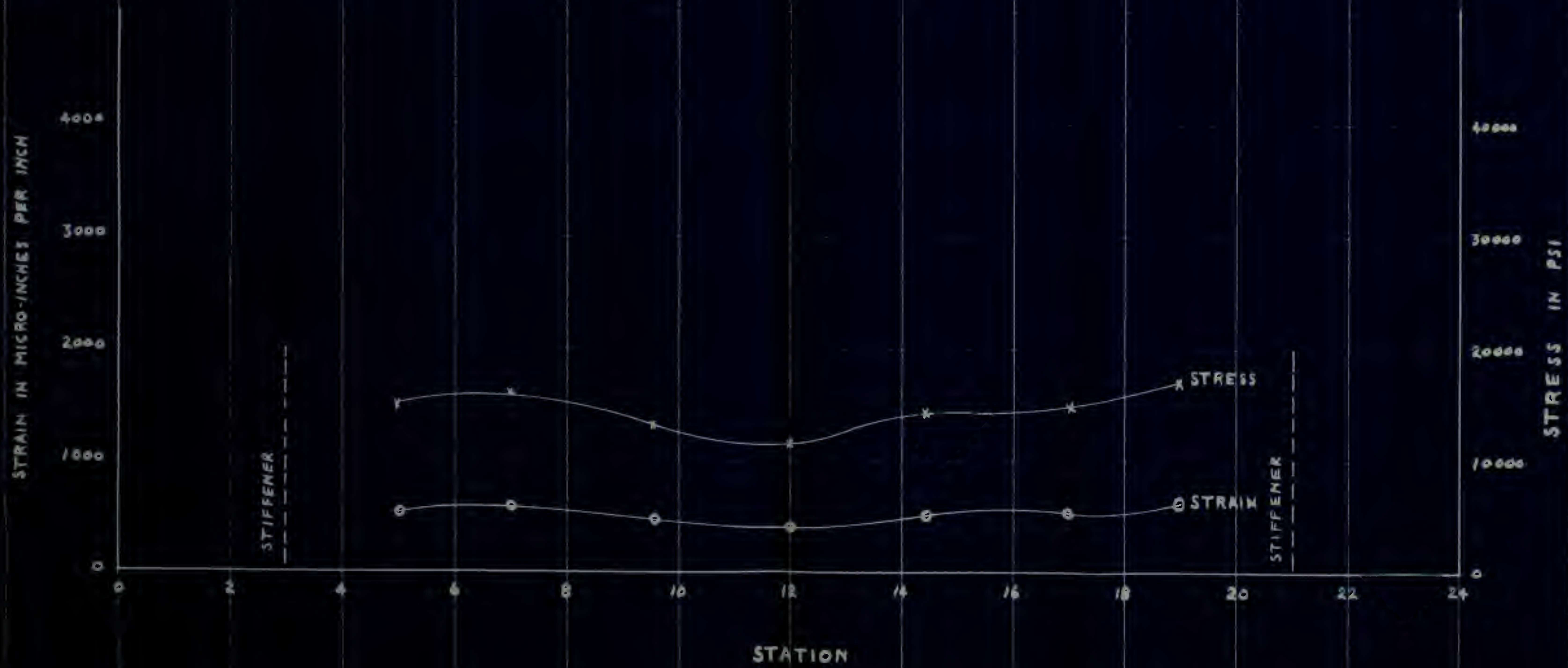
FIGURE XXXV
PANEL I WITH UNIFORM STRAIN OF
1500 MICRO-INCHES PER INCH IN EDGE
(31,400 PSI)
SHOWING MID-PANEL MID-THICKNESS
STRESSES AND STRAINS.
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STRESS
STRAIN
STIFFENER
STIFFENER
0
1000
2000
3000
4000
5000
0
10000
20000
30000
40000
50000
0 2 4 6 8 10 12 14 16 18 20 22 24
STATION



K.E.W.
FIGURE XXXVI
PANEL I WITH UNIFORM STRAIN OF 2000 MICRO-INCHES PER INCH IN EDGE (37,000 PSI)
SHOWING MID-PANEL MID-THICKNESS STRESSES AND STRAINS.
STRAIN
STRESS
STIFFENER
STIFFENER
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STATION
0
1000
2000
3000
4000
5000
6000
7000
10,000
20,000
30,000
40,000
50,000
60,000
70,000
0
2
4
6
8
10
12
14
16
18
20
22
24

FIGURE XXXVII

PANEL 2 WITH UNIFORM STRAIN OF 500 MICRO-INCHES PER INCH IN EDGE (14,000 PSI)
SHOWING MID-PANEL MID-THICKNESS STRESSES AND STRAIN.



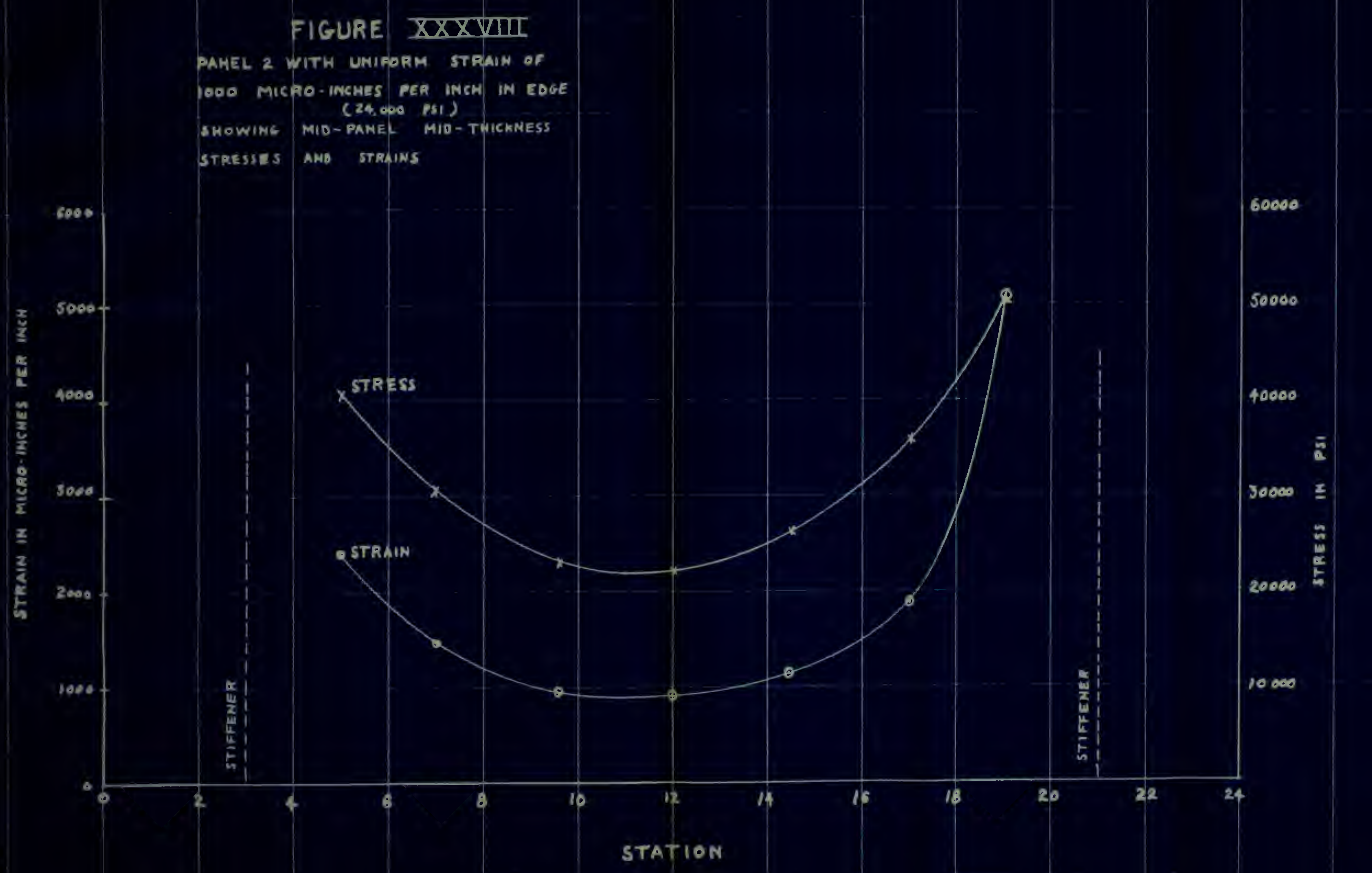


FIGURE XXXVIII
PANEL 2 WITH UNIFORM STRAIN OF
1000 MICRO-INCHES PER INCH IN EDGE
(24,000 PSI)
SHOWING MID-PANEL MID-THICKNESS
STRESSES AND STRAINS
STRESS
STRAIN
STIFFENER
STIFFENER
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STATION
0
1000
2000
3000
4000
5000
6000
10000
20000
30000
40000
50000
60000
0
2
4
6
8
10
12
14
16
18
20
22
24

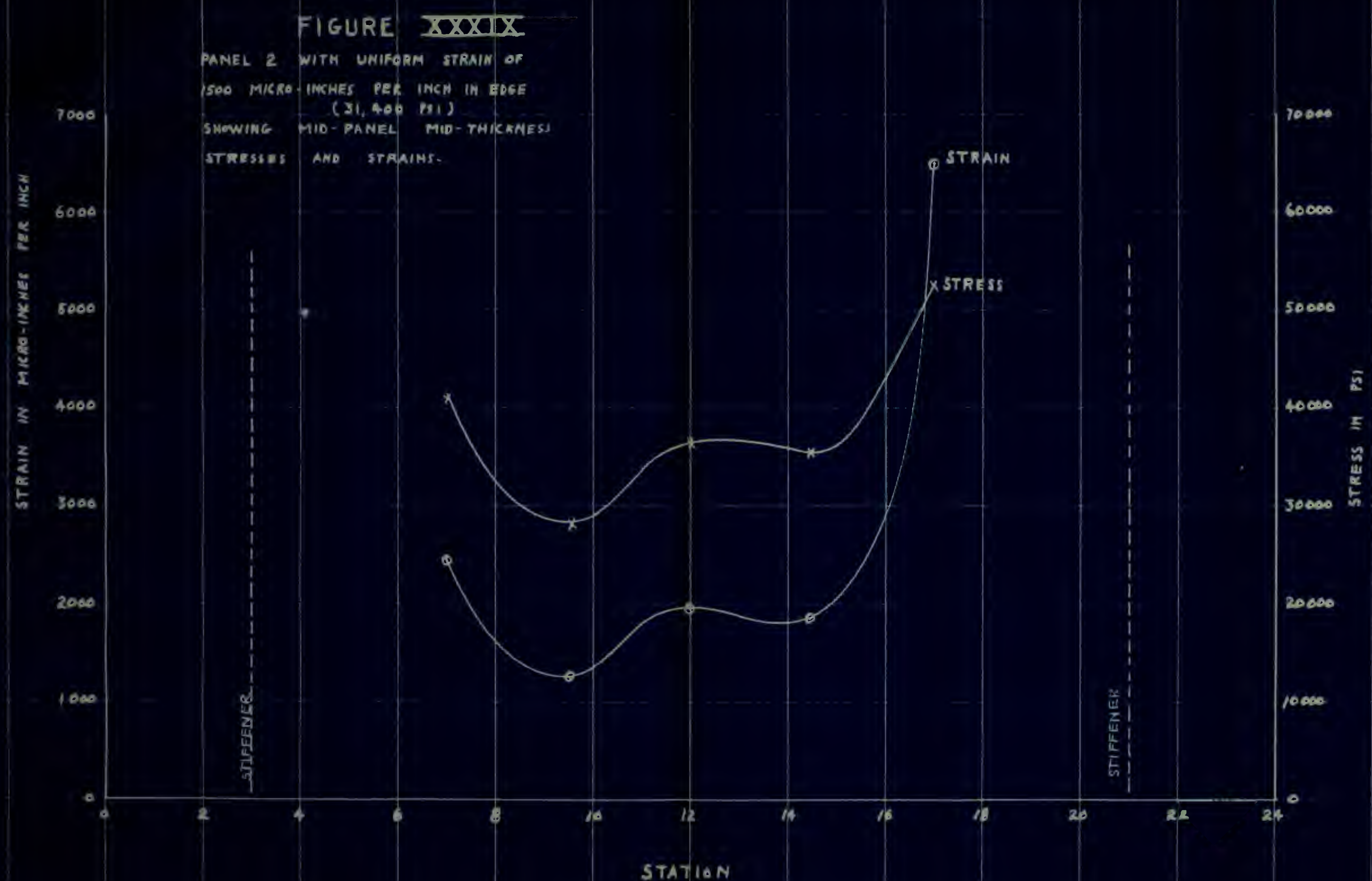


FIGURE XXXIX
PANEL 2 WITH UNIFORM STRAIN OF
1500 MICRO-INCHES PER INCH IN EDGE
(31,400 PSI)
SHOWING MID-PANEL MID-THICKNESS
STRESSES AND STRAINS.
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STRAIN
STRESS
STIFFENER
STIFFENER
STATION
0
1000
2000
3000
4000
5000
6000
7000
10000
20000
30000
40000
50000
60000
70000
2
4
6
8
10
12
14
16
18
20
22
24

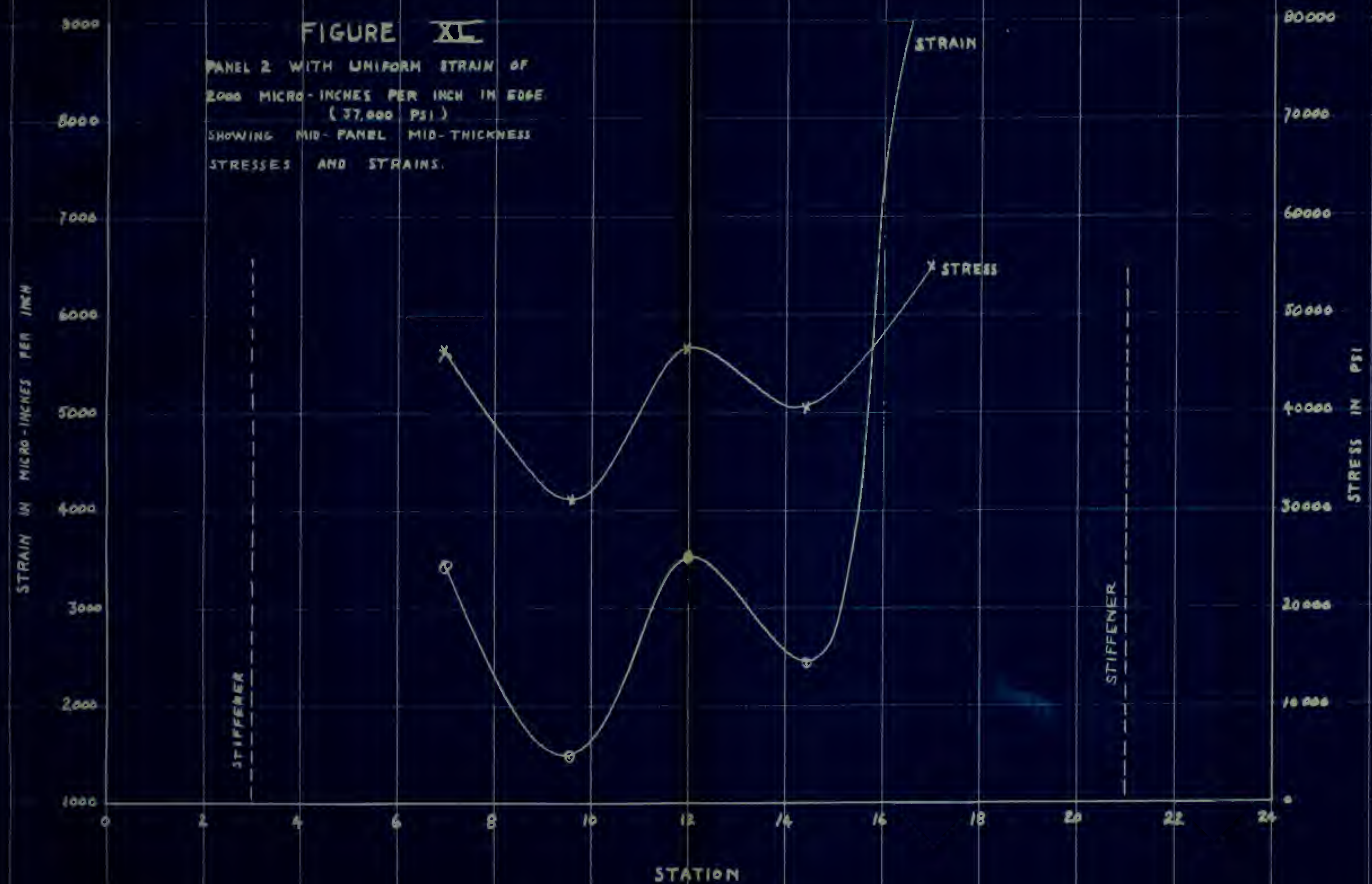


FIGURE XI
PANEL 2 WITH UNIFORM STRAIN OF
2000 MICRO-INCHES PER INCH IN EDGE
(37,000 PSI)
SHOWING MID-PANEL MID-THICKNESS
STRESSES AND STRAINS.
STRAIN
STRESS
STIFFENER
STIFFENER
STRAIN IN MICRO-INCHES PER INCH
STRESS IN PSI
STATION
9000
8000
7000
6000
5000
4000
3000
2000
1000
80000
70000
60000
50000
40000
30000
20000
10000
0
0
2
4
6
8
10
12
14
16
18
20
22
24

III RESULTS

The results of this investigation are summarized by the uniform strain curves, Figures XXXIII - XXXVI for Panel 1 and Figures XXXVII - XL for Panel 2.

3.1 Results of Test on Panel 1

The curves depicting the lower values of uniform strain (Figures XXXIII and XXXIV) show a fairly uniform strain distribution across the center of the panel. This strain is about 1.5 times the uniform strain at the edge.

At 1500 micro-inches per inch uniform strain (Figure XXXV) the strain distribution across the panel is uniform with the exception of the large strain at station 18. The average strain across the center (excluding the reading at station 18) is about twice the edge strain.

At 2000 micro-inches per inch (Figure XXXVI) the strain at station 18 is again higher than the strain at the other stations. Station 20 is not plotted since the cross-curve did not give a value corresponding to this edge strain.

3.2 Results of Test on Panel 2

At 500 micro-inches per inch uniform strain (Figure XXXVII) the center section shows a fairly uniform strain pattern about equal in magnitude to the edge strain.

The strain in the center section corresponding to 1000 micro-inches per inch uniform edge strain shows a decided variation from a

uniform pattern (see Figure XXXVIII). The highest strain is observed closest to the stiffeners where it reaches a value of five times the edge strain.

Figures XXXIX and XL (corresponding to 1500 and 2000 micro-inches per inch strain respectively) show similar strain patterns. The strain is high near the longitudinal stiffener, goes to a minimum, rises at the center, hits another low point, and rises to another high as it approaches the other longitudinal stiffener. The value of the maximum strain point plotted, at station 19, is about four times the 1500 micro-inch per inch uniform edge loading and five times the 2000 micro-inch per inch uniform strain.

IV DISCUSSION OF RESULTS

There are two points that should be mentioned before embarking on a general discussion of the strain patterns determined corresponding to uniform tensile loading.

4.1 Surface Strain Considerations

All of the strain curve drawn represent average, or heart-of-plate, values for the panels concerned. A study of the strain patterns as determined on the panel surfaces themselves is necessary to the understanding of the phenomena which occurred during the tests. The strain gages on the edges of the plate generally showed correspondence for both panels. The strain for both sides increased in proportion to the increasing load and the gages in corresponding positions indicated strains close enough in magnitude to indicate that tension and not bending was the principal condition. In the same fashion the center of plate strain on opposite sides of Panel 1 showed good correspondence. On Panel 1 gages 4 and 22, 5 and 21, and 6 and 20 were in corresponding locations on opposite sides of the panel. At the 120,000 pound load, for example, the ratio of the principal strains at those three locations was 1.27:1, 1.17:1 and 1.17:1 respectively. This indication of a primarily tensile load is evident throughout the test of Panel 1.

However Panel 2 shows a wide difference in strain readings at corresponding locations on opposite sides of the panel in the center section. On Panel 2 gages 10 and 29, 11 and 30, 12 and 31, 13 and 32, and 14 and 33 were located in corresponding locations on opposite sides

of the plate. Reference to Figures XII and XIII will show that these gages were located in the middle section of the span between the longitudinal stiffeners. The strains on the concave side of the panel (gages 10 - 14) reached very high strain values (up to 10,000 micro-inches per inch at 140,000 pounds load) while the gages on the convex side showed compressive strains at first and eventually tensile strains of small magnitude (see Table XVIII). A graphical representation of the situation can be seen on Figure XVIII where these principal strain readings are plotted as crosses on the unstiffened side and triangles on the stiffened side. These extremes of strain, particularly evident on Panel 2 were not considered in the preparation of the uniform strain curves. Therefore we must conclude that strains in excess of those determined for Panel 2 do exist on one surface of the plate. These strains are in the region of the unsupported span between longitudinal stiffeners on the concave side. However the regions of highest strain were determined to be near the longitudinal stiffeners where it was found that the strain readings on both sides of the panel were of the same order of magnitude. We may then regard the cross-sectional area through the plate over which high strains were obtained as being triangular in shape. The two sides of the panel near the longitudinal stiffeners provide two vertices of the triangle and the concave side of the panel in the middle section of the span between longitudinal stiffeners provides the third.

4.2 Bowing of Transverse Stiffeners

The bowing of the transverse stiffeners of Panel 1 as described in paragraph 2.7 is believed to have been caused by the action of the pulling members under load. The bowing of the horizontal portion of the pulling

member caused the ends of the test section to move toward one another, thus forcing the transverse stiffeners to bow. During the test of Panel 2 the horizontal portion of the pulling member did not bow as much as on Panel 1 and the resulting bowing of the transverse stiffeners was noticeably less. It is considered that more uniform loading could be obtained by redesign of the pulling members so as to reduce the amount of bowing in the horizontal portion.

4.3 Discussion of Uniform Strain Curves

4.3.1 The 500 micro-inch per inch uniform strain curves. (Figures XXXIII and XXXVIII).

At low magnitudes of strain any effect that the distortion of Panel 2 had on the strain pattern is not discernible. Strain patterns for Panels 1 and 2 appear to be about the same, essentially a uniform strain across the center of the panel.

4.3.2 The 1000 micro-inch per inch uniform strain curves. (Figures XXXIV and XXXVIII).

Panel 1 continues to indicate a uniform strain pattern across the center of the plate. The unfairness of Panel 2 appears to have commenced to markedly affect the strain distribution. The plotted strain nearest to stiffener increased to 5000 micro-inches per inch and to 4000 nearest to the other stiffener.

4.3.3 The 1500 micro-inch per inch uniform strain curves. (Figures XXXV and XXXIX).

Figure XXXV still continues to show uniform strain across the

center except for the point at station 18. Reference to Figures XXIV and XVI shows the possibility of an error in obtaining this point. The value of the center of plate point would be greatly altered by a slightly different mean strain curve drawn through the known points. Because of the paucity of points the curve is not known with much accuracy so it was not considered justifiable to alter the previously constructed curve.

The strain pattern of Panel 2 (Figure XXXIV) assumes an extremely interesting shape when compared with the transverse section through the center of the panel (Figure XI). The similarity of the two curves is quite noticeable. The points of minimum strain correspond to the points of maximum deflection, and the highest strains are found adjacent to the longitudinal stiffeners.

4.3.4 The 2000 micro-inch per inch uniform strain curves. (Figures XXXVI and XL).

The uniform strain curve for Panel 1 reaches a high point at station 18. Since a value for station 20 corresponding to this value of edge strain was not available (see Figure XXV), the impression is gained that strain is increasing as it approaches the stiffener at station 21. It is probable that station 20 would be more in line with the other stations, and thus expose the point at station 18 as being in error, as was indicated in paragraph 4.3

The strain pattern for Panel 2 retains the same shape and similarity to Figure XI as was noted for the 1500 micro-inches per square inch uniform strain curve.

Note the extremely high strain, and correspondingly large stress near the stiffeners while the bulged portion still does not carry its full share of the load.

V CONCLUSIONS

It is not considered practical for the authors to come to any quantitative conclusions on the basis of the two samples tested. Panel 1 was tested to obtain general information and to help find the most suitable location for gages for future tests. The gage locations for Panel 2 are considered to have given information to more accurately prepare the plots needed for the analysis. The results appear to confirm that strain and stress distribution is related to the plate distortion as was hypothesized at the commencement of this work. This relationship is particularly emphasized by the results of the test of Panel 2. The irregular contour of the panel and the strain picture at high loads which follows that contour lend credence to the hypothesis. It is hoped that future investigations will quantitatively develop the relationships which appear to exist.

V CONCLUSIONS

It is not considered practical for the authors to come to any quantitative conclusions on the basis of the two samples tested. Panel 1 was tested to obtain general information and to help find the most suitable location for gages for future tests. The gage locations for Panel 2 are considered to have given information to more accurately prepare the plots needed for the analysis. The results appear to confirm that strain and stress distribution is related to the plate distortion as was hypothesized at the commencement of this work. This relationship is particularly emphasized by the results of the test of Panel 2. The irregular contour of the panel and the strain picture at high loads which follows that contour lend credence to the hypothesis. It is hoped that future investigations will quantitatively develop the relationships which appear to exist.

VI RECOMMENDATIONS

The work on this project has only begun if the type of results envisioned are to be achieved. Therefore the following recommendations for future work are suggested:

6.1 A plane sample should be tested with more strain gages located in the center section and along the edge. The results of the test of Panel 1 indicate that symmetry was not present and that bending did occur. In addition more points are needed in order to plot the variation of strain across the plane panel with sufficient accuracy to prepare the cross-curves.

6.2 More samples, with varying degrees of bulge, and eventually varying aspect ratios, should be tested.

6.3 The possibility of modifying the design of the pulling members to obtain a more uniform load condition at the edges should be investigated. The possibilities of using thicker gusset plates and/or a stiffer horizontal member are suggested. It should be realized however, that the basic problem of obtaining uniform tension along the edge of a plate, using a machine which essentially gives a point load source may never be fully solved.

6.4 The use of an overall strain measurement, such as can be obtained by use of a Berry Gage (or similar mechanical strain indicator) is suggested. This reading should be taken over the length of the test section in the longitudinal direction. This strain can then be compared to the strains obtained by the SR-4 gages. The possibility of using these Berry Gage readings to construct the uniform strain curve should be considered.

Berry Gage readings were taken during the test of Panel 2 at stations 3, 12, and 21 between points located on the horizontal portions of the pulling members using a gage length of 14-1/4 inches. The strains determined from these readings were consistently larger than corresponding strains obtained from SR-4 gage readings. It was felt that these inaccuracies were introduced by the strain in the weld metal joining the test section and pulling member so the Berry Gage data was not used.

6.5 The use of strain gages on the flanges and webs of the longitudinal stiffeners is also recommended. Verification of the test data could then be made by integrating the stress curves for both the center and loaded edge portions of the test section. The resulting values of load should correspond and should agree with the load imposed by the testing machine. Such data taken only on the outside of the flanges was insufficient to make this procedure possible for the test of Panel 2.

6.6 The ultimate form of the results is seen as a plot of dimensionless bulge (bulge magnitude divided by plate thickness) versus a stress concentration factor. This factor would be the maximum stress existing in the plate divided by the uniform stress along the edge. A third parameter could conceivably be aspect ratio.

VII. APPENDIX

APPENDIX A

Test Data

Table I SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 1						
	Zero Reading			20,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	5900	7360	6410	6005	7420	6380
2	5970	6410	7390	6250	6575	7350
3	6220	7390	8080	6380	7440	8010
4	5950	7050	8220	6320	7210	8100
5	6220	6880	7110	6620	7010	7020
6	4990	4710	6650	5430	4910	6570
7	3780	4770	5370	3990	4835	5260
8	6280	5750	5030	6370	5790	5010
9	6580	6215	6290	6800	6290	6270
10	5200	7130	6950	5460	7290	6850
11	6900	6070	7020	7150	6170	6950
12	5920	7570	7080	6000	7600	7060
13	5110	5870	6650	5280	5940	6600
14	7080	5900	5420	7350	6040	5370
15	7000	7140	7950	7400	7300	7830
16	7090	4950	4380	7340	4990	4310
17	8315	7120	5680	8410	7150	5645
18	3440	4710	5820	3600	4780	5790
19	4300	6780	7180	4480	6810	7150
20	7460	6020	5625	7660	6110	5560
21	7650	7280	4260	7800	7290	4130
22	4430	6840	6790	4670	6890	6700
23	7280	5600	5550	7430	5660	5520
24	4840	6900	6260	4930	6910	6200
25	5780	6510	4890	5870	5510	4865
26	6600	5440	4400	6900	5510	4340
27	4125	6160	6490	4200	6180	6470

Table I SR-4 Indicator Readings

(Micro inches per inch)

	Panel No. 1					
	40,000 Pounds			60,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	6150	7520	6350	6290	7620	6300
2	6580	6735	7280	6880	6890	7190
3	6550	7510	7980	6710	7600	7970
4	6840	7420	7920	7520	7660	7600
5	7400	7320	6890	8280	7620	6490
6	6070	5130	6340	6830	5230	5950
7	4170	4910	5200	4340	4970	5140
8	6440	5850	4990	6530	5940	4980
9	7060	6370	6220	7280	6440	6170
10	5640	5435	6760	5910	7570	6670
11	7475	6240	6805	7810	6300	6690
12	6110	7610	7040	6220	7620	7020
13	5410	5995	6580	5530	6050	6560
14	7620	6170	5280	7910	6310	5200
15	7835	7520	7695	8250	7750	7570
16	7600	4990	4210	7850	5000	4120
17	8560	7210	5610	8720	7295	5570
18	3710	4840	5770	3820	4910	5750
19	4640	6850	7160	4800	6900	7180
20	8140	6300	5430	8830	6430	5030
21	8410	7530	4020	9150	7810	3630
22	5080	7000	6550	5660	7160	6250
23	7610	5760	5550	7800	5910	5610
24	5010	6910	6170	5080	6910	6150
25	5970	5550	4840	6070	5580	4810
26	7260	5610	4200	7640	5740	4080
27	4280	6210	6460	4370	6270	6450

Table I SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 1						
	80,000 Pounds			100,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	6450	7750	6270	6620	7910	6220
2	7190	7050	7120	8310	7930	6740
3	6910	7710	7970	7140	7840	7850
4	8160	7900	7460	7630	8300	7650
5	9730	8180	5720	11900	8810	5010
6	7670	5490	5550	9600	6750	4620
7	4530	5050	5110	4730	5130	5080
8	6630	6050	4950	6740	6180	4950
9	7490	6490	6120	7750	6500	6060
10	6760	7780	6410	7580	8260	6160
11	8120	6330	6600	8420	6340	6520
12	6350	7620	7000	6510	7610	6870
13	5655	6100	6540	5810	6160	6530
14	8230	6490	5110	9520	7500	4690
15	8760	8020	7450	9290	8260	7380
16	8070	5060	4070	8430	5160	4070
17	8900	7400	5530	9100	7520	5490
18	3950	4970	5750	4090	5060	5735
19	5000	6990	7250	5220	7080	7320
20	9560	6710	4710	11170	7515	3900
21	10440	8370	2880	A-2900	8970	2150
22	6170	7300	6160	6490	7570	6325
23	8050	6090	5690	8350	6305	5780
24	5150	6940	6150	5240	6950	6160
25	6200	5630	4790	6360	5710	4760
26	7950	5900	4000	8210	6050	3980
27	4490	6340	6430	4610	6430	6420

Table I SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 1

Gage No.	120,000 Pounds A Axis	120,000 Pounds B Axis	120,000 Pounds C Axis	140,000 Pounds A Axis	140,000 Pounds B Axis	140,000 Pounds C Axis
1	6840	8080	6180	7160	8270	6150
2	10410	9630	6450	A-3380	10790	6310
3	7670	7970	7010	8370	8160	7760
4	10630	9430	6960	A-3190	10080	6590
5	A-3570	9180	4775	A-5530	9830	4340
6	A-3680	7050	3120	A-5030	7660	7940
7	5090	5250	4910	5870	5430	4500
8	6910	6350	4920	7160	6530	4880
9	8130	6500	6160	8900	6650	6330
10	8790	8890	5810	A-2030	9630	5470
11	8980	6530	6460	A-1200	7280	6370
12	6750	7620	6920	7130	7680	6850
13	6040	6230	6510	6340	6300	6470
14	11450	8750	4170	A-3810	9220	3900
15	10160	8530	7330	A-2050	8930	6770
16	10320	5480	3940	A-3330	6180	3570
17	9380	7620	5440	9900	7720	5220
18	4340	5200	5630	4730	5220	5550
19	5570	7280	7410	6160	6560	7420
20	A-4920	8360	2670	A-6790	9230	2340
21	A-4010	9390	2000	A-6020	10160	1660
22	8180	8250	6020	10600	9050	5530
23	8730	6500	5860	9090	6570	5935
24	5430	6970	6120	5780	6930	6010
25	6600	5790	4700	7050	5820	4530
26	8770	6300	4000	A-0830	6560	3950
27	4810	6530	6390	5100	6580	6330

Table II SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 2

Gage No.	Zero Readings A Axis	Zero Readings B Axis	Zero Readings C Axis	20,000 Pounds A Axis	20,000 Pounds B Axis	20,000 Pounds C Axis
1	7340	6700	4750	7390	6740	4750
2	6860	3330	5750	6980	3420	5710
3	6670	7200	6180	6990	7370	6110
4	6950	6700	5030	7260	6830	4930
5	5350	6060	3700	5650	6110	3650
6	8580	6630	7620	8800	6650	7590
7	7960	5240	4810	8120	5280	4780
8	7180	6770	7590	7320	6780	7510
9	5620	5270	5110	5940	5400	5050
10	8370	8010	6580	8870	8230	6520
11	6980	7000	6830	7520	7220	6720
12	7170	7280	4800	7900	7610	4700
13	6440	5560	5150	7020	5850	5050
14	8590	6190	6580	9010	6340	6500
15	7350	7420	5410	7680	7470	5320
16	5440	6770	5360	5590	6780	5270
17	7040	6790	5750	7110	6780	5730
18	7660	7900	6050	7830	7920	6050
19	8110	6530	6630	8580	6780	6570
20	6860	4960	6150	6840	4990	6150
21	4780	4720	6030	4930	4860	6020
22	5770	7180	8470	4820	7320	8450
23	-	-	-	-	-	-
24	6020	4690	7130	6370	4830	7070
25	5680	6230	7770	5950	6260	7710
26	5450	6330	8320	5660	6330	8280
27	5350	4450	5550	5520	4460	5510
28	5370	5350	6430	5400	4350	6360
29	4180	5810	5900	4070	5700	5750
30	4280	6490	8030	4300	6490	7930
31	4980	4950	7980	4820	4780	7800
32	7400	7110	7150	4350	5980	6760
33	4270	6000	6870	4350	5980	6760
34	4550	6800	6360	4720	6850	6320
35	3980	4860	6790	4060	4840	6760
36	5940	4300	7240	6120	4420	7140
37	6070			6060		
38	6320			6430		
39	6930			7360		
40	6640			6870		
41	6680			6790		
42	4410			4610		
B1	0.443"			0.443"		
B2	0.415"			0.403"		
B3	0.344"			0.343"		

Table II SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 2						
	40,000 Pounds			60,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	7530	6830	4740	7680	6910	4740
2	7160	3540	5660	7360	3640	5620
3	7380	7530	6040	7800	7700	6000
4	7680	7050	4840	8140	7310	4760
5	5960	6190	3590	6280	6250	3510
6	9030	6720	7560	9250	6790	7550
7	8280	5330	4760	8440	5380	4740
8	7520	6810	7400	7740	6860	7280
9	6320	6570	4990	6720	5720	4910
10	9420	8490	6460	10000	8750	6380
11	8030	7450	6590	8540	7670	6450
12	8610	7950	4610	9600	8430	4540
13	7610	6130	4970	8490	6640	4910
14	9440	6480	6400	9690	6580	6310
15	7900	7550	5220	8690	7780	5060
16	5800	6820	5150	6110	6890	5050
17	7210	6790	5710	7330	6810	5680
18	8060	7980	6050	8330	8060	6050
19	9510	7290	6540	A-1390	7690	6410
20	6940	5070	6160	7120	5180	6120
21	5130	5010	6010	5330	5150	6010
22	6080	7440	8410	6270	7540	8370
23	-	-	-	-	-	-
24	6750	5060	7010	7100	5290	6970
25	6180	6280	7630	6390	6280	7530
26	5820	6350	8240	5980	6380	8200
27	5710	4500	5490	5880	4550	5480
28	5440	5350	6280	5500	5350	6200
29	4000	5600	5890	3960	5490	5420
30	4400	6500	7810	4560	6560	7720
31	4740	4690	7640	4660	4580	7480
32	7180	6740	7820	7100	6480	7610
33	4490	5960	6630	4800	6000	6460
34	4930	6930	6260	5620	7350	6150
35	4160	4840	6720	4270	4840	6680
36	6280	4540	7080	6640	4650	6920
37	6060			5940		
38	6350			6220		
39	7460			7460		
40	6850			6780		
41	6730			6630		
42	4690			4670		
B1	0.425"			0.396"		
B2	0.367"			0.320"		
B3	0.324"			0.288"		

Table II SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 2						
	80,000 Pounds			100,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	7850	7000	4720	8040	7080	4720
2	7570	3740	5590	7750	3840	5580
3	8540	7950	5940	10110	5820	8480
4	8680	7670	4680	9250	8070	4620
5	6710	6280	3360	7400	6340	3120
6	9440	6860	6580	9630	6910	7610
7	8600	5430	4730	8790	5480	4710
8	8030	6920	7150	8430	7000	6970
9	7690	6180	4810	9160	6860	4710
10	A-1790	9400	6310	A-3460	10200	6320
11	9050	7880	6230	9430	8000	5890
12	A-2180	9330	4480	A-4680	10470	4370
13	9630	7270	4850	A-1330	7910	4780
14	10270	6710	6190	A-3110	7330	5840
15	10570	8190	4860	A-2550	8750	4680
16	6600	7040	4920	7160	7180	4740
17	7470	6840	5650	7600	6850	5620
18	8600	8140	6060	8850	8200	6090
19	A-3180	8580	6130	A-5200	9780	5840
20	7320	5320	6100	7530	5460	6090
21	5540	5280	6010	5730	5410	6040
22	6460	7630	8340	6620	7700	8340
23	-	-	-	-	-	-
24	7410	5560	6940	7660	5850	6950
25	6590	6210	7370	6910	6090	7110
26	6100	6420	8180	6210	6460	8180
27	6010	4580	5500	6130	4590	5540
28	5530	5380	6120	5680	5420	5930
29	3820	5310	5210	3870	5250	4900
30	4750	6680	7690	5160	6910	7680
31	4670	4460	7220	5160	4560	6920
32	7120	6180	7380	7400	5970	7160
33	5500	6280	6270	7690	7230	5940
34	7450	8450	6060	9080	9450	5980
35	4380	4850	6650	4470	4830	6620
36	7380	4760	6630	8360	5010	6210
37	5910			5920		
38	6080			6030		
39	7450			7570		
40	6730			6750		
41	6510			6490		
42	4650			4750		
B1	0.359"			0.335"		
B2	0.265"			0.216"		
B3	0.249"			0.216"		

Table II SR-4 Indicator Readings

(Micro inches per inch)

Panel No. 2						
	120,000 Pounds			140,000 Pounds		
Gage No.	A Axis	B Axis	C Axis	A Axis	B Axis	C Axis
1	8260	7200	4720	8500	7330	4720
2	7990	3930	5550	8190	3960	5460
3	A-2680	9950	5380	A-4980	11800	A-950
4	10180	8600	4510	A-2870	9540	3950
5	8830	6870	3040	10600	7610	2780
6	9910	7020	7640	10120	7150	7680
7	9030	5510	4650	9370	5710	4530
8	8920	7070	6180	9520	7150	6570
9	A-1320	7560	4590	A-2500	8040	4490
10	A-5000	10780	6370	A-6170	A-1870	6400
11	9990	8320	5510	A-2100	9190	4910
12	A-8160	A-2520	4050		A-3820	3250
13	A-2450	8440	4780	A-4470	9280	4810
14	A-7120	9080	5140	A-9930	9980	4690
15	A-3940	9450	4490	A-5360	9980	4300
16	7790	7320	4520	8390	7430	4250
17	7780	6860	5570	8040	6890	5500
18	9140	8270	6130	9490	8390	6190
19	A-6860	A-0300	5450	A-8720	10310	4960
20	7790	5630	6060	8130	5820	5990
21	5950	5580	6140	6200	5790	6260
22	6830	7690	8280	7490	7790	8070
23	-	-	-	-	-	-
24	8110	6190	6890	9780	6760	6410
25	7750	6150	6950	9030	6410	6750
26	6420	6490	8160	6940	6510	8070
27	6290	4630	5590	6450	4670	5610
28	6100	5470	5690	7080	5670	5440
29	4330	5470	4650	5470	6000	4420
30	6320	7380	7610	9270	8650	7630
31	6620	5220	6370	10570	7290	5870
32	8040	6050	7100	9930	6560	6850
33	A-2030	8930	5400	A-4830	9860	5020
34	10610	10150	5890	A-2500	10510	5740
35	4540	4780	6600	4600	4690	6580
36	9350	5350	5830	10580	5730	5410
37	5980			6080		
38	6020			6080		
39	7770			8020		
40	6850			7040		
41	6520			6610		
42	4920			5220		
B1	0.294"			0.244"		
B2	0.140"			0.043"		
B3	0.171"			0.122"		

APPENDIX B

Calculations of Principal Strains

TABLE III
Calculation of Principal Strains

Panel No. 1 Load 20,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½(A+B)	A-D
1	0105	0060	-0030	37.5	67.5
2	0280	0165	-0040	120	160
3	0160	0050	-0070	45	115
4	0370	0160	-0120	125	245
5	0400	0130	-0090	155	245
6	0440	0200	-0080	180	260
7	0210	0065	-0110	50	160
8	0090	0040	-0020	35	55
9	0220	0075	-0020	100	120
10	0260	0160	-0100	80	180
11	0250	0100	-0070	90	160
12	0080	0030	-0020	30	50
13	0170	0070	-0050	60	110
14	0270	0140	-0050	110	160
15	0400	0160	-0120	140	260
16	0250	0040	-0070	90	160
17	0095	0030	-0035	30	65
18	0160	0070	-0030	65	95
19	0180	0030	-0030	75	105
20	0200	0090	-0065	67.5	132.5
21	0150	0010	-0130	10	140
22	0240	0050	-0090	75	165
23	0150	0060	-0030	60	90
24	0090	0010	-0060	15	75
25	0090	0000	-0025	32.5	57.5
26	0300	0070	-0060	120	180
27	0075	0020	-0020	27.5	47.5

TABLE III (continued)
Calculation of Principal Strains

Panel No. 1 Load 20,000 pounds						
	F	G	H	I	J	K
				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
Gage No.	B-D	$(E^2 F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	22.5	71.4	18.4	9.2	109	-34
2	45	166	15.7	7.8	286	-46
3	5	115	2.5	1.2	160	-70
4	35	248	8.1	4.0	373	-123
5	-25	245	-6.0	-3.0	400	-90
6	20	260	4.4	2.2	440	-80
7	15	160	5.4	2.7	210	-110
8	5	55	5.2	2.6	90	-20
9	-25	123	-11.75	-5.9	223	-23
10	80	197	23.9	12	277	-117
11	10	160	0.9	.4	250	-70
12	0	50	0	0	80	-20
13	10	110	5.2	2.6	170	-50
14	30	163	10.6	5.3	273	-53
15	20	268	4.4	2.2	400	-120
16	-50	168	-17.3	-8.6	258	-78
17	0	65	0	0	85	-35
18	5	95	3.0	1.5	160	-30
19	-45	113	-23.4	-11.7	188	-38
20	22.5	135	9.62	4.8	203	-67
21	0	140	0	0	150	-130
22	-25	167	-8.6	-4.3	242	-92
23	0	90	0	0	150	-30
24	-5	75	-3.8	-1.9	90	-60
25	-32.5	66.3	-29.4	-147	99	-34
26	-50	18.7	-15.5	-7.8	307	-67
27	-7.5	48.2	-8.95	-4.5	76	-20

TABLE IV
Calculation of Principal Strains

Panel No. 1 Load 40,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain		
				½ (A+B)	A-D
1	0250	0160	-0060	95	155
2	0610	0325	-0110	250	360
3	0330	0120	-0100	115	215
4	0890	0370	-0300	295	595
5	1180	0440	-0220	480	700
6	1080	0420	-0310	385	695
7	0390	0140	-0170	110	280
8	0160	0100	-0040	60	100
9	0480	0155	-0070	205	275
10	0440	0305	-0190	125	315
11	0575	0170	-0215	180	395
12	0190	0040	-0040	75	115
13	0300	0125	-0070	115	185
14	0540	0270	-0140	200	340
15	0835	0380	-0255	290	545
16	0510	0040	-0170	170	340
17	0245	0090	-0070	88	157
18	0270	0130	-0050	110	160
19	0340	0070	-0020	160	180
20	0680	0280	-0195	242	438
21	0760	0250	-0240	260	500
22	0650	0160	-0240	205	445
23	0330	0160	-0000	165	165
24	0170	0010	-0090	40	130
25	0190	0040	-0050	70	120
26	0660	0170	-0200	230	430
27	0155	0050	-0030	62	93

TABLE IV (continued)
Calculation of Principal Strains

Panel No. 1 Load 40,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2\ F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	65	167	22.7	11.4	262	-72
2	75	368	11.8	5.9	618	-118
3	5	215	1.3	0.7	330	-100
4	75	600	7.2	3.6	895	-305
5	-40	700	-3.3	-1.6	1180	-220
6	35	695	2.9	1.0	1080	-310
7	30	282	6.1	3.0	392	-172
8	40	108	21.8	10.9	168	-48
9	-50	280	-10.3	-5.6	485	-75
10	180	363	29.7	14.8	488	-238
11	-10	395	-1.5	-0.8	575	-215
12	-35	120	-16.9	-8.4	195	-45
13	10	186	5.7	2.8	301	-71
14	70	348	11.6	5.8	548	-148
15	90	553	9.4	4.7	843	-263
16	-130	364	-20.9	-10.4	534	-194
17	2	157	1.5	0.8	245	-69
18	20	161	7.1	3.6	271	-51
19	-90	202	-26.5	-13.2	362	-42
20	38	438	5.0	2.5	680	-196
21	-10	500	-10.2	-5.1	760	-240
22	-45	449	-5.8	-2.9	654	-244
23	-5	165	-1.7	-0.8	330	0
24	-30	133	-13.0	-6.5	173	-93
25	-30	124	-14.0	-7.0	194	-54
26	-60	435	-7.9	-4.0	665	-205
27	-12	94	-7.4	-3.7	156	-32

TABLE V
Calculation of Principal Strains

Panel No. 1 Load 60,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½ (A+B)	A-D
1	0390	0260	-0110	140	250
2	0910	0480	-0200	355	555
3	0490	0210	-0110	140	350
4	1570	0510	-0620	475	1095
5	2060	0740	-0620	720	1340
6	1840	0520	-0700	570	1270
7	0560	0200	-0230	165	395
8	0250	0190	-0050	100	150
9	0700	0225	-0120	290	410
10	0710	0440	-0280	215	495
11	0910	0230	-0330	290	620
12	0300	0050	-0060	120	180
13	0420	0180	-0090	165	255
14	0830	0410	-0220	305	525
15	1250	0610	-0380	435	815
16	0760	0050	-0260	250	510
17	0405	0175	-0110	148	257
18	0380	0200	-0070	155	225
19	0500	0120	-0000	250	250
20	1370	0410	-0595	388	982
21	1500	0530	-0630	435	1065
22	1230	0320	-0540	345	885
23	0520	0310	0060	290	230
24	0240	0010	-0110	65	175
25	0290	0070	-0080	105	185
26	1040	0300	-0320	360	680
27	0245	0110	-0040	102	143

TABLE V (continued)
Calculation of Principal Strains

Panel No. 1 Load 60,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2 F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	-120	278	-25.6	-12.8	418	-138
2	125	569	12.7	6.4	924	-214
3	70	357	11.3	5.6	497	-217
4	35	1095	1.8	.9	1570	-620
5	20	1340	.9	.4	2060	-620
6	-50	1270	-2.3	-1.2	1840	-700
7	35	395	5.1	2.6	560	-230
8	90	175	30.9	15.4	275	-75
9	-65	415	-9.0	-4.5	705	-125
10	225	545	24.4	12.2	760	-330
11	-60	620	-5.6	-2.8	910	-330
12	-70	194	-21.2	-10.6	314	-74
13	15	255	3.4	1.7	420	-90
14	105	536	11.3	5.6	841	-231
15	175	835	12.1	6.0	1270	-400
16	-200	548	-21.4	-10.7	798	-298
17	27	258	6.0	3.0	406	-110
18	45	230	11.3	5.6	385	-75
19	-130	282	-27.4	-13.7	532	-32
20	22	982	1.3	.6	1370	-594
21	95	1065	5.1	2.6	1500	-630
22	-25	885	-1.6	-.8	1230	-540
23	20	230	5.0	2.5	520	60
24	-55	184	-17.4	-8.7	249	-119
25	-35	189	-10.7	-5.4	294	-84
26	-60	680	-5.1	-2.6	1040	-320
27	8	143	3.2	1.6	245	-41

TABLE VI
Calculation of Principal Strains

Panel No. 1 Load 80,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½ (A+B)	A-D
1	0550	0390	-0140	205	345
2	1220	0640	-0270	475	745
3	0690	0320	-0110	290	400
4	2210	0850	-0760	725	1485
5	3510	1300	-1390	1060	2450
6	2680	0780	-1100	790	1890
7	0750	0280	-0260	245	505
8	0350	0300	-0080	135	215
9	0910	0275	-0170	370	540
10	1560	0650	-0540	510	1050
11	1220	0260	-0420	400	820
12	0430	0050	-0080	175	255
13	0545	0230	-0110	218	327
14	1150	0590	-0310	420	730
15	1760	0880	-0500	630	1130
16	0980	0110	-0310	335	645
17	0585	0280	-0150	218	367
18	0510	0260	-0070	220	290
19	0700	0210	0070	315	385
20	2100	0690	-0915	598	1502
21	2790	1090	-1380	705	2085
22	1740	0460	-0630	555	1185
23	0770	0490	0140	315	455
24	0310	0040	-0110	100	210
25	0420	0120	-0100	160	260
26	1350	0460	-0400	475	875
27	0365	0180	-0060	152	213

TABLE VI (continued)
Calculation of Principal Strains

Panel No. 1 Load 80,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2 F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	185	392	28.2	14.1	737	-47
2	165	763	12.5	6.3	1238	-288
3	30	400	4.3	2.2	610	-110
4	125	1485	4.9	2.4	2210	-760
5	240	2450	5.6	2.8	3510	-1390
6	-10	1890	0	0	2680	-1100
7	35	505	4.0	2.0	750	-260
8	165	271	37.5	18.8	406	-136
9	-95	546	-10.0	-5.0	9116	-176
10	140	1060	7.6	3.8	1570	-550
11	-140	834	-9.7	-4.8	1234	-434
12	-125	284	-26.2	-13.1	459	-109
13	12	327	2.1	1.0	545	-109
14	170	751	13.1	6.6	1171	-331
15	250	1160	12.5	6.2	1790	-530
16	-225	684	-19.2	-9.6	1019	-349
17	62	372	9.6	4.8	590	-154
18	40	294	7.8	3.9	514	-74
19	-105	399	-15.2	-7.6	714	84
20	92	1502	3.5	1.8	2100	-904
21	385	2120	10.4	5.2	2825	-1415
22	-95	1185	-4.6	-2.3	1740	-630
23	175	488	21.0	10.5	803	-173
24	-60	219	-15.9	-8.0	319	-119
25	-40	263	-8.8	-4.4	423	-103
26	-15	875	-1.0	-0.5	1350	-400
27	28	215	7.5	3.8	367	-63

TABLE VII

Calculation of Principal Strains

Panel No. 1 Load 100,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½ (A+B)	A-D
1	0720	0550	-0190	265	455
2	2340	1520	-0650	845	1495
3	0920	0450	-0130	395	525
4	2680	1250	-0570	1055	2150
5	5680	1930	-2100	1790	3890
6	4610	1540	-2030	1290	3320
7	0150	0360	-0290	330	620
8	0460	0430	-0080	190	270
9	1170	0285	-0230	470	700
10	2580	1130	-0790	895	1685
11	1520	0270	-0500	510	1010
12	0590	0040	-0110	240	350
13	0700	0290	-0120	290	410
14	2440	1600	-0730	855	1585
15	2290	1120	-0570	585	1705
16	1340	0210	-0310	515	825
17	0785	0400	-0190	298	487
18	0650	0350	-0085	282	368
19	0920	0300	0140	530	390
20	3710	1495	-1725	992	2720
21	4710	1690	-2110	1300	3410
22	2060	0730	-0465	798	1262
23	1070	0705	0230	650	420
24	0400	0050	-0100	150	250
25	0580	0200	-0130	225	355
26	1610	0610	-0420	595	1015
27	0485	0270	-0070	208	277

TABLE VII (Continued)
Calculation of Principal Strains

Panel No. 1 Load 100,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2\ F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	285	538	32.0	16.0	803	-273
2	675	1640	24.3	12.2	2485	-795
3	55	529	5.96	3.0	924	-134
4	195	2150	5.2	2.6	3205	-1095
5	140	3890	2.1	1.0	5680	-2100
6	250	3320	4.3	2.2	4610	-2030
7	30	620	2.8	1.4	950	-290
8	240	361	41.6	20.8	551	-171
9	-185	724	-14.8	-7.4	1194	-254
10	235	1710	7.92	4.0	2605	-815
11	-240	1040	-13.35	6.7	1550	-530
12	-200	404	-29.7	14.8	644	-160
13	0	410	0	0	700	-120
14	1215	1750	25.2	12.6	2605	-895
15	535	1790	17.4	8.7	2375	-1205
16	-305	881	-20.25	-10.1	1396	-366
17	102	499	11.8	5.9	797	-201
18	68	375	10.45	5.2	657	-93
19	-230	453	-30.5	-15.2	983	77
20	503	2770	10.45	5.2	3762	-1778
21	390	3450	6.5	3.2	4750	-2150
22	-68	1262	-3.1	-1.6	2060	-464
23	55	424	7.45	2.7	1074	226
24	-100	270	-21.8	-10.9	420	-120
25	-25	355	-4.0	-2.0	580	-130
26	15	1015	.85	.4	1610	-420
27	62	284	12.6	6.3	492	-76

TABLE VIII
Calculation of Principal Strains

Panel No. 1 Load 120,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½ (A+B)	A-D
1	0940	0720	-0230	355	585
2	4440	3220	-0940	-1750	2690
3	1450	0580	-0170	640	810
4	4680	2380	-1260	1710	2970
5	6810	2300	-2335	2238	4572
6	8150	2340	-3530	2310	5840
7	1310	0480	-0460	425	885
8	0630	0600	-0110	260	370
9	1550	0285	-0130	710	840
10	3590	1760	-1140	1225	2365
11	2080	0360	-0560	760	1320
12	0830	0050	-0160	335	495
13	0930	0360	-0140	395	535
14	4370	2850	-1250	1560	2810
15	3160	1390	-0620	1270	1890
16	3230	0530	-0440	1395	1835
17	1065	0500	-0240	412	653
18	0900	0490	-0190	355	545
19	1270	0500	-0230	520	750
20	6920	2340	-2955	1982	4938
21	5820	2110	-2260	1780	4040
22	3750	1410	-0770	1490	2260
23	1450	0900	0310	570	880
24	0590	0070	-0140	225	365
25	0820	0280	-0190	315	505
26	2170	0860	-0400	885	1285
27	0685	0370	-0100	292	393

TABLE VIII (continued)
Calculation of Principal Strains

Panel No. 1 Load 120,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2 F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	365	690	32.0	16.0	1045	-335
2	1470	3060	28.7	14.4	4810	-1310
3	-60	810	-4.3	-2.2	1450	-170
4	670	3040	12.7	6.4	4750	-1330
5	62	4572	0.8	0.4	6810	-2334
6	30	5840	0	0	8150	-3530
7	55	885	3.6	1.8	1310	-460
8	340	502	42.6	21.3	767	-242
9	-425	933	-26.8	-13.4	1643	-223
10	535	2420	12.8	6.4	3645	-1195
11	-400	1373	-16.9	-8.4	1533	-613
12	-285	570	-30.0	-15.0	905	-335
13	-35	535	-3.8	-1.9	930	-140
14	1290	3150	24.7	12.4	4710	-1590
15	120	1890	3.6	1.8	3160	-620
16	-865	2030	-25.2	-12.6	3425	-635
17	88	660	7.7	3.8	1072	-248
18	135	560	13.9	7.0	915	-205
19	-20	750	-1.5	-0.8	1270	-230
20	358	4938	4.1	2.0	6920	-2956
21	330	4040	4.7	2.4	5820	-2260
22	-80	2260	-2.0	-1.0	3750	-770
23	330	940	20.5	10.2	1510	-370
24	-155	397	-23.0	-11.5	622	-172
25	-35	505	-4.0	-2.0	820	-190
26	-25	1285	-1.1	-0.6	2170	-400
27	78	400	11.2	5.6	692	-7

TABLE IX
Calculation of Principal Strains

Panel No. 1 Load 140,000 pounds					
	A	B	C	D	E
Gage No.	A axis strain	B axis strain	C axis strain		
				½(A+B)	A-D
1	1260	0910	-0260	500	760
2	6870	4380	-1080	2895	3975
3	2150	0770	-0320	915	1235
4	6640	3030	-1630	2505	4135
5	8770	2950	-2770	3000	5770
6	9500	2950	-3710	2895	6605
7	2090	0660	-0870	610	1480
8	0880	0780	-0150	365	515
9	2320	0435	0040	1180	1140
10	6290	2500	-1480	2405	3885
11	3760	1210	-0650	1555	2205
12	1210	0110	-0230	490	720
13	1230	0430	-0180	525	705
14	6190	3320	-1440	2375	3815
15	4510	1790	-1180	1665	2845
16	5700	1230	-0810	2445	3255
17	1585	0600	-0460	562	1023
18	1290	0510	-0270	510	780
19	1860	0780	0240	1050	810
20	8790	3210	-3285	2752	6040
21	7830	2880	-2600	2615	5215
22	6170	2210	-1260	2455	3715
23	1110	0970	0385	748	362
24	0940	0030	-0250	345	595
25	1270	0310	-0360	455	815
26	3690	1120	-0450	1620	2070
27	0975	0420	-0160	408	567

TABLE IX (Continued)
Calculation of Principal Strains

Panel No. 1 Load 140,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2 F^2)^{\frac{1}{2}}$	Arc Tan F/E	½ H	D+G	D-G
1	410	865	28.3	14.2	1365	-365
2	1485	4240	20.5	10.2	7135	-1345
3	-145	1250	-6.69	-3.3	2165	-335
4	525	4170	7.22	3.6	6675	-1665
5	-50	5770	-5.0	-2.5	8770	-2770
6	55	6605	4.8	2.4	9500	-3710
7	50	1570	18.6	1.3	2180	-960
8	415	662	- 38.8	19.4	1027	-297
9	-745	1360	-33.2	-16.6	2540	-180
10	95	3890	1.4	0.7	6295	-1485
11	-345	2230	-8.88	-4.4	3785	-675
12	-380	814	-27.8	-13.9	1304	-324
13	-95	713	-7.66	-3.83	1238	-188
14	945	3930	13.9	7.0	6305	-1555
15	125	2845	2.5	1.2	4510	-1180
16	-1215	3470	-20.5	-10.2	5915	-1025
17	38	1023	2.1	1.0	1585	-461
18	0	780	0	0	1290	-270
19	-270	856	-18.4	-92	1906	194
20	458	6040	4.4	2.2	8792	-3288
21	265	5215	2.9	1.5	7830	-2600
22	-245	3720	-3.8	-1.9	6175	-1265
23	222	425	31.5	15.8	1173	323
24	-315	674	-27.9	-14.0	1019	-329
25	-145	826	-10.1	-5.0	1281	-371
26	-500	2130	-13.55	-6.8	3750	-510
27	12	567	1.2	.6	975	-159

TABLE X

Calculation of Principal Strains

Panel No. 2 Load 20,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A–D
1	50	40	0	25	25
2	120	90	-40	40	80
3	320	170	-70	125	70
4	310	130	-100	105	205
5	300	50	-50	125	175
6	220	20	-30	95	125
7	160	40	-30	65	95
8	140	10	-80	30	110
9	320	130	-60	130	190
10	500	220	-60	220	280
11	540	220	-110	215	325
12	730	330	-100	315	415
13	580	290	-100	240	340
14	420	150	-80	170	250
15	250	50	-90	80	170
16	150	10	-90	30	120
17	70	-10	-20	25	45
18	170	20	0	85	85
19	470	250	-60	205	265
20	-20	30	0	-10	-10
21	150	140	-10	70	80
22	150	140	-20	65	85
23					
24	350	140	-60	145	205
25	270	30	-60	105	165
26	210	0	-40	135	75
27	170	10	-40	115	55
28	30	0	-70	-20	10
29	-110	-110	-150	-130	20
30	20	0	-100	-40	60
31	-160	-170	-180	-170	10
32	-130	-180	-160	-145	15
33	80	-20	-110	-15	65
34	170	50	-40	65	105
35	80	-20	-30	25	55
36	180	120	-100	40	140
37	-10				
38	110				
39	430				
40	230				
41	110				
42	200				

TABLE X (continued)
Calculation of Principal Strains

Panel No. 2 Load 20,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	15	29	30.7	15.4	54	-4
2	50	95	31.8	15.9	135	-55
3	45	84	32.5	16.2	209	41
4	25	209	6.9	3.4	314	-104
5	-75	192	-23.0	-11.5	317	-67
6	-75	147	-30.7	-15.4	242	-52
7	-25	99	-14.2	-7.1	164	-34
8	-20	113	-10.2	-5.1	143	-83
9	0	190	0	0	320	-60
10	0	280	0	0	500	-60
11	5	325	0.9	.4	540	-110
12	15	415	2.1	1.0	730	-100
13	50	347	8.3	4.2	587	-107
14	-20	250	-4.6	-2.3	420	-80
15	-30	174	-9.9	-5.0	254	-94
16	-20	123	-9.4	-4.7	153	-93
17	-35	57	-37.6	-18.8	82	-32
18	-65	107	-37.2	-18.6	192	-22
19	-45	271	-9.6	-4.8	476	-66
20	40	42	104.0	52	32	-52
21	70	107	40.9	20.4	177	-37
22	75	114	41.2	20.6	179	-49
23						
24	-5	205	-1.4	-0.7	350	-50
25	-75	183	-24.2	-12.1	288	-78
26	-135	156	-61.2	-30.6	291	-21
27	-105	120	-62.6	-31.3	235	-5
28	20	26	67.5	33.8	6	-46
29	20	28	45	22.5	-102	-158
30	40	73	33.4	16.7	33	-113
31	0	10	0	0	-160	-180
32	-35	38	-67	-33.5	-107	-183
33	-5	65	-4.4	-2.2	50	-80
34	-15	107	-8.0	-4.0	172	-42
35	-45	71	-39.0	-19.5	96	-46
36	80	162	29.5	14.8	202	-122

TABLE XI

Calculation of Principal Strains

Panel No. 2 Load 40,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A-D
1	190	130	-10	90	100
2	300	210	-90	105	195
3	710	330	-140	285	425
4	730	350	-190	270	460
5	610	130	-110	250	360
6	450	90	-60	195	255
7	320	90	-50	135	185
8	340	40	-190	75	265
9	700	300	-120	290	410
10	1050	480	-120	465	585
11	1050	450	-240	405	645
12	1440	670	-190	625	815
13	170	570	-180	-5	175
14	850	290	-180	335	515
15	550	130	-190	180	370
16	360	50	-210	75	285
17	170	0	-40	65	105
18	400	80	0	200	200
19	1400	760	-90	655	745
20	80	110	10	45	35
21	350	290	-20	165	185
22	310	260	-60	125	185
23					
24	730	370	-120	305	425
25	500	50	-140	180	320
26	370	20	-80	145	225
27	360	50	-60	150	210
28	70	0	-150	-40	110
29	-180	-210	-310	-245	65
30	120	10	-220	-50	170
31	-240	-260	-340	-290	50
32	-220	-370	-330	-275	55
33	220	-40	-240	-10	230
34	380	130	-100	140	240
35	180	-20	-70	45	135
36	340	240	-160	90	250
37	-70				
38	30				
39	530				
40	210				
41	50				
42	280				

TABLE XI

Calculation of Principal Strains

	Panel No. 2 Load 40,000 pounds				
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+C)	A-D
1	190	130	-10	90	100
2	300	210	-90	105	195
3	710	330	-140	285	425
4	730	350	-190	270	460
5	610	130	-110	250	360
6	450	90	-60	195	255
7	320	90	-50	135	185
8	340	40	-190	75	265
9	700	300	-120	290	410
10	1050	480	-120	465	585
11	1050	450	-240	405	645
12	1440	670	-190	625	815
13	170	570	-180	-5	175
14	850	290	-180	335	515
15	550	130	-190	180	370
16	360	50	-210	75	285
17	170	0	-40	65	105
18	400	80	0	200	200
19	1400	760	-90	655	745
20	80	110	10	45	35
21	350	290	-20	165	185
22	310	260	-60	125	185
23					
24	730	370	-120	305	425
25	500	50	-140	180	320
26	370	20	-80	145	225
27	360	50	-60	150	210
28	70	0	-150	-40	110
29	-180	-210	-310	-245	65
30	120	10	-220	-50	170
31	-240	-260	-340	-290	50
32	-220	-370	-330	-275	55
33	220	-40	-240	-10	230
34	380	130	-100	140	240
35	180	-20	-70	45	135
36	340	240	-160	90	250
37	-70				
38	30				
39	530				
40	210				
41	50				
42	280				

TABLE XI (continued)
Calculation of Principal Strains

Panel No. 2 Load 40,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	40	109	21.6	10.8	199	-19
2	105	223	28.1	14.0	328	-118
3	45	431	6.0	3.0	716	-146
4	80	471	9.8	4.9	741	-201
5	-120	383	-18.3	-9.2	633	-133
6	-105	278	-22.2	-11.1	473	-83
7	-45	191	-16.6	-6.8	326	-56
8	-35	270	-7.4	-3.7	345	-195
9	10	410	1.4	0.7	700	-120
10	15	585	1.5	0.8	1050	-120
11	45	645	4.0	2.0	1050	-240
12	45	815	3.2	1.6	1440	-190
13	575	605	73.2	36.6	600	-610
14	-45	515	-5.0	-2.5	850	-180
15	-50	376	-7.6	-3.8	556	-194
16	-25	285	-5.0	-2.5	360	-210
17	-65	124	-31.5	-15.8	189	-59
18	-120	234	-30.8	-15.4	434	-34
19	105	760	7.8	4.0	1415	-105
20	65	74	61.9	31.0	119	-29
21	125	225	33.8	16.9	390	-60
22	135	230	35.9	18.0	355	-105
23						
24	65	434	8.6	4.3	739	-129
25	-130	348	-21.9	-11.4	528	-168
26	-125	259	-28.8	-14.4	404	-114
27	-100	234	-25.3	-12.6	384	-84
28	40	118	19.8	9.9	78	-158
29	35	74	28.1	14.0	-171	-319
30	60	182	19.3	9.6	132	-232
31	30	58	30.8	15.4	-232	-348
32	-95	111	-60.2	-30.1	-164	-386
33	-30	234	-7.4	-3.7	224	-244
34	-10	240	-2.4	-1.2	380	-100
35	-65	151	-25.5	-12.8	196	-106
36	150	293	30.8	15.4	383	-203

TABLE XII
Calculation of Principal Strains

Panel No. 2 Load 60,000 pounds					
	A	B	C	D	E
Gage	A Axis strain	B Axis strain	C Axis strain	$\frac{1}{2}$ (A+B)	A–D
1	340	210	-10	165	175
2	500	310	-130	185	315
3	1130	500	-180	475	655
4	1190	610	-270	460	730
5	930	190	-190	370	560
6	670	160	-80	295	375
7	480	140	-70	205	275
8	560	90	-310	125	435
9	1100	450	-200	450	650
10	1630	740	-200	715	915
11	1560	670	-380	590	970
12	2430	1150	-260	1085	1345
13	2050	1080	-240	905	1145
14	1100	390	-570	265	835
15	1340	360	-350	495	845
16	670	120	-310	180	490
17	290	20	-70	110	180
18	670	160	0	335	335
19	2740	1430	-220	1260	1480
20	260	220	-30	115	135
21	550	430	-20	265	285
22	500	360	-100	200	300
23					
24	1080	600	-160	460	620
25	710	50	-240	235	475
26	530	50	-120	205	325
27	530	100	-70	230	300
28	130	0	-230	-50	180
29	-220	-320	-480	-350	130
30	280	70	-310	-15	295
31	-320	-370	-500	-410	90
32	-300	-630	-540	-420	120
33	530	0	-410	60	470
34	1070	550	-210	430	640
35	290	-20	-110	90	200
36	700	350	-320	140	560
37	-130				
38	-100				
39	530				
40	140				
41	-50				
42	260				

TABLE XII
Calculation of Principal Strains

	Panel No. 2 Load 60,000 pounds				
	A	B	C	D	E
Gage	A Axis strain	B Axis strain	C Axis strain		
				½ (A+B)	A-D
1	340	210	-10	165	175
2	500	310	-130	185	315
3	1130	500	-180	475	655
4	1190	610	-270	460	730
5	930	190	-190	370	560
6	670	160	-80	295	375
7	480	140	-70	205	275
8	560	90	-310	125	435
9	1100	450	-200	450	650
10	1630	740	-200	715	915
11	1560	670	-380	590	970
12	2430	1150	-260	1085	1345
13	2050	1080	-240	905	1145
14	1100	390	-570	265	835
15	1340	360	-350	495	845
16	670	120	-310	180	490
17	290	20	-70	110	180
18	670	160	0	335	335
19	2740	1430	-220	1260	1480
20	260	220	-30	115	135
21	550	430	-20	265	285
22	500	360	-100	200	300
23					
24	1080	600	-160	460	620
25	710	50	-240	235	475
26	530	50	-120	205	325
27	530	100	-70	230	300
28	130	0	-230	-50	180
29	-220	-330	-480	-350	130
30	280	70	-310	-15	295
31	-320	-370	-500	-410	90
32	-300	-630	-540	-420	120
33	530	0	-410	60	470
34	1070	550	-210	430	640
35	290	-20	-110	90	200
36	700	350	-320	140	560
37	-130				
38	-100				
39	530				
40	140				
41	-50				
42	260				

TABLE XII (continued)
Calculation of Principal Strains

Panel No. 2 Load 60,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B–D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D–G
1	45	182	14.3	7.2	347	-17
2	125	342	21.5	10.8	527	-157
3	25	655	2.2	1.1	1130	-180
4	150	753	11.5	5.8	1213	-293
5	-180	592	-17.7	-8.8	962	-222
6	-135	403	-19.6	-9.8	698	-108
7	-65	285	-13.2	-6.6	490	-80
8	-35	435	-4.6	-2.3	560	-310
9	0	650	0	0	1100	-200
10	25	915	1.6	0.8	1630	-200
11	80	970	4.7	2.4	1560	-380
12	-35	1345	-1.5	-0.8	2430	-260
13	175	1170	8.6	4.3	2075	-265
14	125	850	8.45	4.2	1115	-585
15	-135	863	-9.0	-4.5	1358	-368
16	-60	498	-6.9	-3.4	678	-318
17	-90	202	-26.4	-13.2	312	-92
18	-175	381	-27.4	-13.7	716	-46
19	170	1500	6.5	3.2	2760	-240
20	105	172	37.6	18.8	287	-57
21	165	332	29.8	14.9	597	-67
22	160	342	27.9	14.0	542	-142
23						
24	140	642	12.6	6.3	1102	-182
25	-185	514	-21.1	-10.6	749	-279
26	-155	363	-25.3	-12.6	568	-158
27	-130	330	-23.2	-11.6	560	-100
28	50	188	15.4	7.7	138	-238
29	30	134	12.9	6.4	-216	-484
30	85	310	15.9	8.0	295	-325
31	40	99	23.8	11.9	-311	-509
32	-210	243	-60.4	-30.2	-177	-663
33	-60	480	-7.2	-3.6	540	-420
34	120	656	10.5	5.2	1086	-226
35	-110	230	-28.6	-14.3	320	-140
36	210	604	20.4	10.2	744	-464

Table XIII
Calculation of Principal Strains

Panel No. 2 Load 80,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A–D
1	510	300	-30	240	270
2	710	-410	-160	275	435
3	1870	750	-240	815	1055
4	1730	970	-350	690	1040
5	1360	220	-340	570	790
6	860	230	-40	410	450
7	640	190	-80	280	360
8	850	150	-440	205	645
9	2070	910	-300	885	1185
10	2880	1390	-270	1305	1575
11	2070	880	-600	735	1335
12	4470	2050	-320	2075	2395
13	3190	1710	-300	1445	1745
14	1680	520	-390	645	1035
15	3220	770	-550	1335	1885
16	1160	270	-440	360	800
17	430	50	-100	165	265
18	940	240	10	475	465
19	4530	2050	-500	2015	2515
20	460	360	-50	205	255
21	760	560	-20	370	390
22	690	450	-130	280	410
23					
24	1390	870	-190	600	790
25	910	-20	-400	255	655
26	650	90	-140	255	395
27	660	130	-50	305	355
28	160	30	-310	-75	235
29	-360	-500	-690	-525	165
30	470	190	-340	65	405
31	-310	-490	-760	-535	225
32	-280	-930	-770	-525	245
33	1230	280	-600	315	915
34	2900	1650	-300	1300	1600
35	400	-10	-140	130	270
36	1440	460	-610	415	1025
37	-160				
38	-240				
39	520				
40	90				
41	-170				
42	240				

TABLE XIII(continued)
Calculation of Principal Strains

Panel No. 2 Load 80,000						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	60	280	12.4	6.2	520	-40
2	135	460	17.1	8.6	735	-185
3	-65	1055	-3.5	1.8	1870	-240
4	300	1090	16.0	8.0	1780	-400
5	-350	870	-23.7	-11.8	1440	-300
6	-180	490	-21.6	-10.8	900	-80
7	-90	375	-13.9	-7.0	655	-95
8	-55	645	-4.9	-2.4	850	-440
9	25	1185	1.5	0.8	2070	-300
10	85	1575	3.1	1.6	2880	-270
11	145	1350	6.2	3.1	2085	-615
12	-25	2395	-0.6	-0.3	4470	-320
13	265	1780	8.6	4.3	3225	-335
14	-125	1050	-6.8	-3.4	1695	-405
15	-565	1990	-16.5	-8.2	3325	-655
16	-90	814	-6.8	-3.4	1174	-454
17	-115	291	-23.2	-11.6	456	-126
18	-235	525	-26.6	-13.3	1000	-50
19	35	2515	0.8	0.4	4530	-500
20	155	301	31.0	15.5	506	-96
21	190	437	25.8	12.9	807	-67
22	170	448	22.3	11.2	728	-168
23						
24	270	843	18.7	9.4	1443	-243
25	-275	716	-22.6	-11.3	971	-461
26	-165	432	-22.5	-11.2	687	-177
27	-175	400	-26.0	-13.0	705	-95
28	105	260	23.9	12.0	185	-335
29	25	168	8.5	4.2	-357	-693
30	125	428	17.0	8.5	493	-363
31	45	232	11.2	5.6	-303	-767
32	-405	476	-59.0	-29.5	-49	-1001
33	-35	915	2.2	1.1	1230	-600
34	350	1660	12.2	6.1	2960	-360
35	-140	305	27.4	13.7	435	-175
36	45	1025	2.5	1.2	1440	-610

Table XIV
Calculation of Principal Strains

Panel No. 2 Load 100,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A-D
1	700	380	-30	335	365
2	890	510	-170	360	530
3	3440	1280	-360	1540	1900
4	2300	1370	-410	945	1355
5	2050	280	-580	735	1315
6	1050	280	-10	520	530
7	830	240	-100	365	465
8	1250	230	-620	315	935
9	3540	1590	-400	1570	1970
10	4550	2190	-260	2145	2405
11	2450	1000	-940	755	1695
12	6970	3190	-430	3270	3700
13	4350	2350	-370	2140	2210
14	3980	1140	-1740	1120	2860
15	4660	1330	-730	1965	2695
16	1720	410	-620	550	1170
17	560	60	-130	215	345
18	1190	300	40	615	575
19	6550	2650	-790	2880	3670
20	670	500	-60	305	365
21	950	690	10	480	470
22	850	520	-130	360	490
23					
24	1640	1160	-180	730	910
25	1230	-140	-660	285	945
26	760	130	-140	310	450
27	780	140	-10	385	395
28	310	70	-500	-95	405
29	-310	-560	-1000	-655	345
30	880	420	-350	265	615
31	180	-390	-1060	-440	620
32	0	-1140	-990	-495	495
33	3420	1230	-930	1245	2175
34	4530	2650	-380	2075	2455
35	490	-30	-170	160	330
36	2420	710	-1030	695	1725
37	-150				
38	-290				
39	640				
40	110				
41	-190				
42	340				

TABLE XIV (continued)
Calculation of Principal Strains

Panel No. 2 Load 100,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	45	368	7.0	3.5	703	-33
2	150	550	15.9	8.0	910	-190
3	-260	2000	-7.6	-3.8	3540	-460
4	425	1420	17.5	8.8	2365	-475
5	-455	1390	-19.1	-9.6	2125	-655
6	-240	581	-24.4	-12.2	1101	-61
7	-125	480	-15.1	-7.6	845	-115
8	-85	935	-5.1	-2.6	1250	-620
9	20	1980	5.8	2.9	3550	-410
10	45	2405	1.0	0.5	4550	-260
11	245	1710	8.2	4.1	2465	-955
12	-80	3700	-1.3	-0.6	6970	-430
13	210	2210	5.5	2.8	4350	-70
14	20	2860	4.0	2.0	3980	-1740
15	-635	2770	-13.2	-6.6	4735	-805
16	-140	1180	-6.9	-3.4	1730	-630
17	-155	378	-24.2	-12.1	593	-163
18	-315	665	-28.7	-14.4	1280	-50
19	-230	3670	-3.6	-1.8	6550	-790
20	195	413	28.2	14.1	718	-108
21	210	515	24.1	12.0	995	-35
22	160	515	18.1	9.0	875	-155
23						
24	430	1005	25.3	12.6	1735	-275
25	-425	1035	-24.2	-12.1	1320	-750
26	-180	485	-21.8	-10.9	795	-175
27	-245	475	-31.8	-15.9	860	-90
28	165	438	22.2	11.1	343	-533
29	95	347	15.9	8.0	-308	-1002
30	155	634	14.2	7.1	899	-369
31	50	620	4.6	2.3	180	-1060
32	-645	813	-52.5	-26.2	318	-1308
33	-15	2175	0	0	3420	-930
34	575	2510	13.1	6.6	4585	-435
35	-190	380	-30.0	-15.0	540	-220
36	15	1725	0	0	2420	-1030

TABLE XV

Calculation of Principal Strains

Panel No. 2 Load 120,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A–D
1	920	500	-30	445	475
2	1130	600	-200	465	665
3	5470	2750	-800	2335	3135
4	3230	1900	-520	1355	1875
5	3480	810	-660	1410	2430
6	1330	390	20	675	655
7	1070	330	-160	455	615
8	1740	300	-810	465	1275
9	5160	2290	-520	2320	2840
10	6090	2770	-210	2940	3150
11	3010	1320	-1320	845	2165
12	10450	4700	-750	4850	5600
13	5470	2880	-370	2550	2920
14	7990	2890	-1440	3275	4715
15	6050	2030	-920	2565	3485
16	2350	550	-840	755	1595
17	740	70	-180	280	460
18	1480	370	80	780	700
19	8210	3230	-1180	3515	4695
20	930	670	-90	420	510
21	1170	860	110	640	530
22	1060	510	-190	435	625
23					
24	2090	1500	-240	925	1165
25	2070	-80	-820	625	1445
26	970	160	-160	405	565
27	940	180	40	490	450
28	730	120	-740	-5	735
29	150	-340	-1250	-550	700
30	2040	890	-420	810	1230
31	1640	270	-1610	15	1625
32	640	-1060	-1050	205	435
33	7220	2930	-1470	2875	4345
34	6060	3350	-470	2795	3265
35	560	-80	-190	185	375
36	3410	1050	-1410	1000	2410
37	-90				
38	-300				
39	840				
40	210				
41	-160				
42	510				

TABLE XV (continued)
Calculation of Principal Strains

Panel No. 2 Load 120,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	55	479	6.6	3.3	924	-34
2	135	678	11.5	5.7	1143	-213
3	415	3160	7.5	3.8	5495	-825
4	545	1950	16.2	8.1	3305	-615
5	-600	2500	-13.7	-6.8	3910	-1090
6	-285	715	-23.5	-11.8	1390	-40
7	-125	628	-11.5	-5.8	1083	-173
8	-165	1280	-7.4	-3.7	1745	-815
9	-30	2840	-0.6	-0.3	5160	-520
10	-170	3150	-3.0	-1.5	6090	-210
11	475	2210	12.4	6.2	3055	-1365
12	-150	5600	-1.5	-0.8	10450	-750
13	330	2940	6.5	3.2	5490	-390
14	-385	4715	-4.7	-2.4	7990	-1440
15	-535	3520	-8.8	-4.4	6085	-955
16	-205	1605	-7.3	-3.6	2360	-850
17	-210	506	-24.5	-12.2	786	-226
18	-410	812	-30.4	-15.2	1592	-32
19	-285	4695	-3.5	-1.8	8210	-1180
20	250	567	26.1	13.0	987	-147
21	220	574	22.5	11.2	1214	66
22	75	630	6.9	3.4	1065	-195
23						
24	575	1300	26.3	13.2	2225	-375
25	-705	1610	-26.0	-13.0	2235	-985
26	-245	615	-23.5	-11.8	1020	-210
27	-310	548	-34.5	-17.2	1038	-58
28	125	745	9.7	4.8	740	-750
29	210	730	16.7	8.4	180	-1280
30	80	1230	3.8	1.9	2040	-420
31	255	1650	8.9	4.4	1665	-1635
32	-1265	1335	-71.0	-35.5	1540	-1095
33	55	4345	0.7	0.4	7220	-1470
34	555	3300	9.7	4.8	6095	-505
35	-265	459	-35.3	-17.6	644	-274
36	50	2410	1.3	0.7	3410	-1410

TABLE XVI (continued)
Calculation of Principal Strains

Panel No. 2 Load 140,000 pounds						
	F	G	H	I	J	K
Gage No.				Angle Principal Strain	Major Principal Strain	Minor Principal Strain
	B-D	$(E^2+F^2)^{\frac{1}{2}}$	Arc Tan F/E	$\frac{1}{2}$ H	D+G	D-G
1	65	600	6.2	3.1	1165	-35
2	110	815	7.8	3.9	1335	-295
3	1330	4690	16.5	8.2	7960	-1420
4	690	3300	12.1	6.0	5450	-1150
5	-615	3140	-11.3	-5.6	5305	-975
6	-280	790	-20.7	-10.3	1590	10
7	-95	850	-6.6	-3.3	1410	-285
8	280	1700	9.5	4.8	2360	-1040
9	-90	3480	-1.5	-0.8	6340	-620
10	-220	3720	-3.4	-1.7	7260	-180
11	-1060	1700	-38.6	-19.3	4950	1550
12						
13	145	3915	2.0	1.0	7490	-340
14	-665	6346	-6.0	-3.0	10801	-1891
15	-620	4330	-8.2	-4.1	7510	-1150
16	-260	2050	-7.3	-3.6	2970	-1130
17	-275	683	-23.8	-11.9	1058	-308
18	-495	980	-30.4	-15.2	1965	5
19	-420	5870	-4.1	-2.0	10070	-1670
20	305	775	23.2	11.6	1330	-220
21	245	643	22.4	11.2	1468	182
22	-50	1060	-2.6	-1.3	1720	-400
23						
24	550	2300	13.8	6.9	3820	-780
25	-985	2400	-24.3	-12.2	3565	-1235
26	-440	975	-26.8	-13.4	1595	-355
27	-360	633	-34.7	-17.4	1213	-53
28	-40	1350	-1.6	-0.8	1710	-990
29	285	1410	11.6	5.8	1315	-1505
30	-85	2745	-1.8	-0.9	4990	-500
31	600	3900	8.9	4.4	5640	-2160
32	1165	2240	31.3	15.6	2855	-1625
33	-225	5935	-2.2	-1.1	10020	-1850
34	315	4015	4.5	2.2	7410	-620
35	-375	511	-47.1	-23.6	716	-306
36	25	3235	0	0	4640	-1830

TABLE XVI

Calculation of Principal Strains

Panel No. 2 Load 140,000 pounds					
	A	B	C	D	E
Gage No.	A Axis strain	B Axis strain	C Axis strain	½ (A+B)	A–D
1	1160	630	-30	565	595
2	1330	630	-290	520	810
3	7770	4600	-1230	3270	4500
4	5380	2840	-1080	2150	3230
5	5250	1550	-920	2165	3085
6	1540	520	60	800	740
7	1410	470	-280	565	845
8	2340	380	-1020	660	1680
9	6340	2770	-620	2860	3480
10	7260	3320	-180	3540	3720
11	4580	2190	1920	3250	1330
12	off scale	6000	-1550		
13	7490	3720	-340	3575	3915
14	10800	3790	-1890	4455	6345
15	7470	2560	-1110	3180	4290
16	2950	660	-1110	920	2030
17	1000	100	-250	375	625
18	1830	490	140	985	845
19	10070	3780	-1670	4200	5870
20	1270	860	-160	555	715
21	1420	1070	230	825	595
22	1720	610	-400	660	1060
23					
24	3760	2070	-720	1520	2240
25	3350	180	-1020	1165	2185
26	1490	180	-250	620	870
27	1100	220	60	580	520
28	1710	320	-990	360	1350
29	1290	190	-1480	-95	1385
30	4990	2160	-500	2245	2745
31	5590	2340	-2110	1740	3850
32	2530	-550	-1300	615	1915
33	10020	2860	-1850	4085	5935
34	7410	3710	-620	3395	4015
35	620	-170	-210	205	415
36	4640	1430	-1830	1405	3235
37	10				
38	-240				
39	1090				
40	400				
41	-70				
42	810				

REW.
1-5-53

TABLE XVII

RESULTS OF ROSETTE CALCULATIONS FOR PANEL ONE SHOWING DIRECTION AND MAGNITUDE OF PRINCIPAL STRAINS AS SEEN BY AN OBSERVER LOOKING AT AND THROUGH THE PANEL FROM THE UNSTIFFENED SIDE.

ANGLE BETWEEN STRAIN AXIS AND "A" AXIS OF PANEL.

PRINCIPAL STRAINS IN MICRO-INCHES PER INCH. TENSION IS POSITIVE.

ROSETTE NUMBER	LOAD IN POUNDS 20,000	40,000	60,000	80,000	100,000	120,000	140,000
1	9.2; 109; -34	11.4; 262; -72	12.8; 418; -138	14.1; 737; -47	16.0; 803; -273	15.0; 1045; -335	14.2; 1365; -365
2	7.8; 281; -46	5.9; 618; -118	6.4; 924; -214	6.3; 1238; -288	12.2; 2485; -795	14.4; 4810; -1310	10.2; 7135; -1345
3	1.2; 160; -70	0.7; 330; -100	5.6; 497; -217	2.2; 690; -110	3.0; 924; -134	2.2; 1450; -170	3.3; 2165; -335
4	4.0; 373; -123	3.6; 395; -305	0.9; 1570; -620	2.4; 2210; -760	2.6; 3205; -1095	6.4; 4750; -1330	3.6; 6675; -1665
5	3.0; 400; -90	1.6; 1080; -220	0.4; 2060; -620	2.8; 3510; -1390	1.0; 5680; -2100	0.4; 6810; -2334	2.5; 8770; -2770
6	2.2; 440; -90	1.5; 1080; -310	1.2; 1840; -700	0.0; 2630; -1100	2.2; 4610; -2030	0.0; 8150; -3530	2.4; 9500; -3710
7	2.7; 210; -110	3.0; 392; -172	2.6; 560; -230	2.0; 750; -240	1.4; 950; -290	1.8; 1310; -460	1.3; 2180; -960
8	2.6; 90; -20	10.9; 168; -48	15.4; 275; -75	18.8; 406; -136	20.8; 551; -171	21.3; 767; -242	19.4; 1027; -297
9	5.9; 222; -23	5.1; 485; -75	4.5; 705; -125	5.0; 916; -176	7.4; 1194; -254	13.4; 1643; -223	16.6; 2540; -180
10	12.0; 217; -117	14.8; 488; -238	12.2; 760; -330	3.8; 1570; -550	4.0; 2605; -815	6.4; 3645; -1195	0.7; 6295; -1485
11	0.4; 250; -10	0.0; 575; -215	2.8; 910; -330	4.8; 1234; -434	6.7; 1550; -530	8.4; 1853; -613	4.4; 3785; -675
12	0.0; 80; -20	8.4; 195; -45	10.6; 314; -74	13.1; 459; -109	14.8; 644; -160	15.0; 905; -335	13.9; 1304; -324

R.E.W.
5-5-53

TABLE XVII (CONT'D)

RESULTS OF ROSETTE CALCULATIONS FOR PANEL ONE SHOWING DIRECTION AND MAGNITUDE OF PRINCIPAL STRAINS AS SEEN BY AN OBSERVER LOOKING AT AND THROUGH THE PANEL FROM THE UNSTIFFENED SIDE.

ROSETTE NUMBER	LOAD IN POUNDS						
	20,000	40,000	60,000	80,000	100,000	120,000	140,000
13	170 2.6 -50	301 2.8 -71	420 1.7 -90	545 1.0 -108	700 0.0 -120	930 1.9 -140	1238 3.8 -188
14	273 5.3 -53	548 5.8 -148	841 6.6 -231	1171 6.6 -331	2605 12.6 -895	4710 12.4 -1500	6305 7.0 -1555
15	400 2.2 -120	843 4.7 -263	1270 6.0 -400	1790 6.2 -530	2375 8.7 -1205	3160 1.8 -620	4510 1.2 -1180
16	258 8.6 -78	534 10.4 -194	798 10.7 -298	1019 9.6 -349	1396 10.1 -366	3425 12.6 -635	5915 10.2 -1025
17	85 0.0 -35	245 0.8 -69	406 3.0 -110	590 4.8 -154	797 5.9 -201	1072 3.8 -248	1585 1.0 -461
18	160 1.5 -30	271 3.6 -51	385 5.6 -75	514 3.9 -84	657 5.2 -93	915 7.0 -205	1230 0.0 -270
19	188 11.7 -38	362 13.2 -42	532 13.7 -32	714 7.6 -84	983 15.2 +77	1290 0.8 -230	1906 9.2 +194
20	203 4.8 -67	680 2.5 -196	1370 0.6 -594	2100 1.8 -904	3672 5.2 -1778	6920 2.0 -2956	8792 2.2 -3288
21	150 0.0 -130	760 5.1 -240	1500 2.6 -630	2825 5.2 -1415	4750 3.2 -2150	5820 2.4 -2260	7830 1.5 -2600
22	242 4.3 -92	654 2.9 -244	1230 0.8 -540	1740 2.3 -630	2060 1.6 -464	3750 1.0 -770	6175 1.8 -1265
23	150 0.0 -30	330 0.8 0	520 2.5 +60	803 10.5 -173	1074 2.7 +226	1510 10.2 -370	1173 15.8 +323
24	80 1.9 -60	173 6.5 -93	249 8.7 -119	319 8.0 -119	420 10.9 -120	622 11.5 -172	1019 14.0 -329
25	99 14.7 -34	194 7.0 -54	294 5.4 -84	423 4.4 -103	580 2.0 -130	820 2.0 -190	1281 5.0 -371
26	307 7.8 -67	665 4.0 -205	1040 2.6 -320	1350 0.5 -400	1610 0.4 -420	2170 0.6 -400	3750 6.8 -510
27	76 4.5 -20	156 3.7 -32	245 1.6 -41	367 3.8 -63	492 6.3 -76	692 5.6 -7	975 0.6 -159

REW

TABLE XVIII

RESULTS OF ROSETTE CALCULATIONS FOR PANEL TWO SHOWING DIRECTION AND MAGNITUDE OF PRINCIPAL STRAINS AS SEEN BY AN OBSERVER LOOKING AT AND THROUGH THE PANEL FROM THE UNSTIFFENED SIDE.

ANGLE BETWEEN STRAIN AXIS AND "A" AXIS OF PANEL

PRINCIPAL STRAINS IN MICRO-INCHES PER INCH. TENSION IS POSITIVE.

Each cell: angle; principal strains (max / min).

ROSETTE NUMBER	LOAD IN POUNDS 20,000	40,000	60,000	80,000	100,000	120,000	140,000
1	15.4; 54 / -4	10.8; 199 / -19	7.2; 347 / -17	6.2; 520 / -40	3.5; 703 / -33	7.3; 924 / -34	3.1; 1165 / -35
2	15.0; 135 / -4	14.0; 328 / -118	10.8; 527 / -157	8.6; 735 / -195	8.0; 910 / -190	5.7; 1143 / -213	3.9; 1335 / -295
3	16.2; 209 / -41	3.0; 716 / -146	1.1; 1130 / -180	1.8; 1870 / -240	3.9; 3540 / -460	3.8; 5486 / -825	8.2; 7960 / -1420
4	3.4; 314 / -104	4.9; 741 / -201	6.8; 1213 / -293	8.0; 1780 / -400	6.8; 2365 / -475	8.1; 3305 / -615	6.0; 5450 / -1160
5	11.5; 317 / -67	9.2; 633 / -133	8.8; 962 / -222	11.8; 1440 / -300	9.6; 2125 / -655	6.8; 3910 / -1090	5.6; 5305 / -975
6	15.4; 242 / -52	11.1; 473 / -83	9.8; 698 / -108	10.8; 900 / -80	12.2; 1101 / -61	11.8; 1390 / -40	10.3; 1590 / +10
7	7.1; 164 / -34	6.8; 326 / -56	6.6; 490 / -80	7.0; 655 / -95	7.6; 845 / -115	5.8; 1083 / -173	3.3; 1410 / -285
8	5.1; 143 / -83	3.7; 345 / -195	2.3; 560 / -310	2.4; 850 / -440	2.6; 1250 / -620	3.7; 1745 / -815	4.8; 2360 / -1040
9	0.0; 320 / -60	0.7; 700 / -120	0.0; 1100 / -200	0.8; 2070 / -300	2.9; 3550 / -410	0.3; 5160 / -520	0.8; 6340 / -620
10	0.0; 500 / -60	0.8; 1050 / -120	0.8; 1650 / -200	1.6; 2880 / -270	0.5; 4550 / -260	1.5; 6090 / -210	1.7; 7260 / -180
11	0.4; 340 / -110	2.0; 1050 / -240	2.4; 1560 / -380	3.1; 2085 / -615	4.1; 2465 / -955	6.2; 3055 / -1365	19.3; 4950 / +1550
12	1.0; 730 / -100	1.6; 1440 / -190	0.8; 2430 / -260	0.3; 4470 / -320	0.6; 6370 / -430	0.8; 10460 / -750	OFF SCALE

REW
5-4-53

TABLE XVIII (CONT'D)

RESULTS OF ROSETTE CALCULATIONS FOR PANEL TWO SHOWING DIRECTION AND MAGNITUDE OF PRINCIPAL STRAINS AS SEEN BY AN OBSERVER LOOKING AT AND THROUGH THE PANEL FROM THE UNSTIFFENED SIDE.

ROSETTE NUMBER	LOAD IN POUNDS 20,000	40,000	60,000	80,000	100,000	140,000	160,000
13	4.2 / 581 / -107	36.6 / 600 / -610	4.3 / 2075 / -265	4.3 / 3225 / -335	2.8 / 4350 / -70	3.2 / 5400 / -390	1.0 / 7490 / -340
14	2.3 / 420 / -80	2.5 / 850 / -180	4.2 / 1115 / -585	3.4 / 1695 / -405	2.0 / 3980 / -1740	2.4 / 7990 / -1440	3.0 / 10 801 / -1891
15	5.0 / 254 / -94	3.8 / 556 / -194	4.6 / 1358 / -368	8.2 / 3325 / -635	6.6 / 4735 / -805	4.4 / 6085 / -965	4.1 / 7510 / -1160
16	4.7 / 153 / -93	2.5 / 360 / -210	3.4 / 678 / -318	3.4 / 1174 / -454	3.4 / 1730 / -630	3.6 / 2360 / -850	3.6 / 2970 / -1130
17	18.8 / 82 / -32	15.8 / 189 / -69	13.2 / 312 / -92	11.6 / 456 / -126	12.1 / 593 / -163	12.2 / 786 / -226	11.9 / 1058 / -308
18	18.6 / 192 / -22	15.4 / 434 / -34	13.7 / 716 / -46	13.3 / 1000 / -50	14.4 / 1280 / -50	15.2 / 1592 / -32	15.2 / 1965 / +5
19	4.8 / 476 / -66	4.0 / 1415 / -105	3.2 / 2760 / -240	0.4 / 4530 / -500	1.8 / 6550 / -750	1.8 / 8210 / -1180	2.0 / 10 070 / -1670
20	52.0 / 32 / -52	31.5 / 119 / -29	18.8 / 287 / -57	15.5 / 506 / -96	14.1 / 718 / -108	13.0 / 987 / -141	11.6 / 1330 / -220
21	20.4 / 177 / -37	16.9 / 390 / -60	14.9 / 597 / -67	12.9 / 807 / -67	12.6 / 995 / -35	11.2 / 1214 / +66	11.2 / 1468 / +182
22	20.6 / 179 / -49	18.0 / 355 / -105	14.0 / 542 / -142	11.2 / 728 / -168	9.0 / 875 / -155	3.4 / 1065 / -195	1.3 / 1720 / -400
24	0.7 / 350 / -50	4.3 / 739 / -129	6.3 / 1102 / -182	9.4 / 1443 / -243	12.6 / 1735 / -275	13.2 / 2225 / -375	6.9 / 3820 / -780
25	12.1 / 288 / -78	11.4 / 528 / -168	10.6 / 749 / -279	11.3 / 971 / -461	12.1 / 1320 / -750	13.0 / 2235 / -985	12.2 / 3565 / -1235
26	30.6 / 201 / -21	14.4 / 404 / -114	12.6 / 568 / -158	11.2 / 687 / -177	10.9 / 795 / -175	11.8 / 1020 / -210	13.4 / 1505 / -355
27	31.3 / 235 / -5	12.6 / 384 / -84	11.6 / 560 / -100	13.0 / 705 / -95	15.9 / 860 / -90	17.2 / 1038 / -58	17.4 / 1213 / -53

R.E.W.
7-4-33

TABLE XVIII (CONT'D.)

RESULTS OF ROSETTE CALCULATIONS FOR PANEL TWO SHOWING DIRECTION AND MAGNITUDE OF PRINCIPAL STRAINS AS SEEN BY AN OBSERVER LOOKING AT AND THROUGH THE PANEL FROM THE UNSTIFFENED SIDE.

ROSETTE NUMBER	LOAD IN POUNDS 20,000	40,000	60,000	80,000	100,000	120,000	140,000
28	33.8: 6 / -46	3.9: 78 / -158	7.7: 138 / -238	12.0: 185 / -335	11.1: 343 / -533	4.8: 740 / -750	0.8: 1710 / -990
29	22.5: -102 / -158	14.8: -171 / -319	6.4: -216 / -484	4.2: -357 / -693	8.0: -308 / -1002	8.4: 180 / -1280	5.8: 1315 / -1505
30	16.7: 33 / -113	8.6: 132 / -232	8.0: 295 / -325	8.5: 493 / -363	7.1: 898 / -369	1.9: 2040 / -420	0.9: 4990 / -500
31	0.0: -160 / -180	15.4: -232 / -348	11.9: -311 / -509	5.6: -303 / -767	2.3: 180 / -1060	4.4: 1665 / -1635	4.4: 5640 / -2160
32	33.5: -107 / -183	30.1: -164 / -336	30.2: -177 / -663	20.5: -49 / -1001	26.2: 318 / -1398	35.5: 1540 / -1095	15.6: 2855 / -1625
33	2.2: 50 / -80	3.7: 224 / -244	3.6: 540 / -420	1.1: 1230 / -600	0.0: 3420 / -930	0.4: 7220 / -1470	1.1: 10820 / -1850
34	4.0: 172 / -42	1.2: 380 / -100	5.2: 1086 / -226	6.1: 2960 / -360	6.6: 4585 / -435	4.8: 6095 / -505	2.2: 7410 / -620
35	19.5: 96 / -46	12.8: 196 / -106	14.3: 320 / -140	13.7: 435 / -175	15.0: 540 / -220	17.6: 644 / -274	23.6: 716 / -386
36	14.8: 202 / -122	15.4: 383 / -203	10.2: 744 / -464	1.2: 1440 / -610	0.0: 2420 / -1030	0.7: 3410 / -1410	0.0: 4640 / -1830
37	-10	-70	-130	-160	-150	-90	+10
38	110	30	-100	-240	-290	-300	-240
39	430	530	530	520	640	840	1090
40	230	210	140	90	110	210	400
41 42	110 / 200	50 / 280	-50 / 260	-170 / 240	-190 / 340	-160 / 510	-70 / 810

APPENDIX D

References

(1). Report of a Board of Investigation Convened by Order of the Secretary of the Navy, "The Design and Methods of Construction of Welded Steel Merchant Ships".

(2). Turnbull, J., "Recent Developments in the Study of Longitudinal Strength", Shipbuilding and Shipping Record, Volume 80, No. 14, October 2, 1952

(3). Society of Automotive Engineers, Incorporated, "SAE Handbook", 1948 Edition.